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MASSACHUSETTS ARMY NATIONAL GUARD

REPORT

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CHARACTERIZATION of EMISSIONS RESULTING FROM THERMAL TREATMENT of SELECTED PROPELLANTS

A Dugway Proving Ground
BangBox Study

January 1994

Final Report!

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EXECUTIVE SUMMARY

The U.S. Army Dugway Proving Ground has completed a series of trials sponsored by the Massachusetts National Guard (MNG) to identify and quantify the emissions produced by the open burning (OB) of two propellants selected and provided by the MNG. The purpose of the test was to obtain emissions data necessary to support permitting of OB operations at Camp Edwards, Massachusetts. The best available technologies were used to detect and quantify emissions, and all detected emissions were identified except for some compounds not in spectra libraries.

The Open Burning/Open Detonation (OB/OD) Thermal Treatment Emissions Study, conducted by the U.S. Army Armament, Munitions and Chemical Command (AMCCOM) validated instruments, equipment, and procedures used to characterize emissions resulting from thermal treatment operations. These technologies were applied during conduct of this test.

All trials were conducted at DPG within a 1000-m³ flexible hemisphere commonly known as the BangBox (BB) using the AMCCOM OB/OD thermal treatment emissions system successfully audited by several environmental agencies. This system consists of the BangBox facility, a technical steering committee to address testing challenges as they appear, and a network of laboratories specializing in the sampling and assay of volatile organic compounds (VOC), semi-volatile compounds (SVOC), and metals as found in the atmosphere at trace levels.

Instruments within the BB chamber and its attached airlock included high-volume samplers, PS-1 samplers, evacuated SUMMATM canisters, real-time gas analyzers, video recorders, and a data acquisition system (DAS). An automatically-regulated blower provided filtered air to keep the BB chamber inflated. A suppressive shield and witness shields prevented test-produced flames from scorching the chamber wall.

The MNG provided M-3/Green Bag and M-9 propellants for testing. Munitions specialists prepared these items for testing in a manner paralleling open-air disposal procedures followed by the MNG at its disposal sites. In most instances, this involved adding a small donor charge of Hercules UniqueTM powder to assist in igniting the propellant.

Laboratory assay was conducted using either supercritical fluid chromatography/mass spectrometry, gas chromatography/mass spectrometry, or both. High performance liquid chromatography was used in a few instances for comparison. Statistical analyses included precise characterization of the BB chamber using results of SF₆ tracer gas released and sampled during each trial, and calculating emission factors (EF) from the results of laboratory assay after considering flow rates as recorded by the DAS, chamber atmosphere dilution as determined from SF₆ concentration data, and background.

The United States Environmental Protection Agency provided quality assurance support for this test. Representatives from its Atmospheric Research and Exposure Assessment Laboratory's Quality Assurance and Technology Division visited the test site and supporting laboratories.

In all instances, almost all carbon in the explosive mixes was converted to CO₂ during the burning processes. All detected emissions were found at very low levels, typically at the ppt or ng range. The EF data, reflecting these low levels, will be of great value when applied to dispersion models and used in risk assessments. Although no sample calculations were performed, it appears likely that these emissions will be non-detectable when dispersed by wind.

The M3 average EF from total nonmethane organic carbon (volatiles) as determined by EPA TO-12 was 0.00018. Selecting benzene as an example for a volatile compound, the average EF was 0.000014 which would equate to 13.4g of benzene produced from a one metric ton burn of M3.

M3 semivolatiles were found at lower levels than the volatiles. 2,4-Dinitrotoluene, an example of a semivolatile which was detected by all 3 assay procedures, gave a high average EF of 0.0000062. This EF equates to 6.2g of 2,4-dinitrotoluene produced from a one metric ton burn of M3.

M9 volatiles were generally at lower levels than those observed with the M3 burns. Styrene (not detected on M3 burn) was detected resulting in an EF of 0.00000047. This equates to 0.47g of styrene from a one metric ton burn of M9.

M9 semivolatiles were generally at lower levels than those observed with the M3 burns and fewer compounds were detected.

The temperature and relative humidity variations between the M3 trials had no effect on the emissions produced or the level of emissions observed.

SECTION 1. INTRODUCTION

1.1. BACKGROUND

1.1.1. Disposal Requirements

As part of their training, soldiers (both Army National Guard and U.S. Army Reserve) open burn excess mortar and artillery propellants at Camp Edwards, a part of the Massachusetts Military Reservation (MMR) (reference 1). Each artillery and mortar round comes supplied with the standard maximum charge of propellant. If all the propellant provided were used, the projectiles could be propelled beyond the Camp Edwards designated impact area. Therefore, following approved standard training requirements, the unneeded propellant is collected each day at each of the firing sites and burned in the immediate proximity of the firing site where it is generated. Open Burning of unopened bags of propellant is the most practical way to dispose of resulting unneeded propellants before they begin to deteriorate or become more sensitive to initiation. In the absence of immediate on-site disposal, propellants accumulate and must be temporarily stored, thus creating a potentially dangerous situation.

1.1.2. Disposal Issues

1.1.2.1. Local citizens in communities adjacent to the MMR have expressed concern about the potential health impacts of this type of training.

1.1.2.2. In April 1991, the U.S. Army Environmental Hygiene Agency (USAEHA) formed an interdisciplinary task force. [comprised of an Occupation Medicine Physician (Task Force Leader), environmental engineer, meteorologist, industrial hygienist, and toxicologist] to evaluate the environmental risks associated with the OB of these propellants at Camp Edwards.

1.1.2.3. This task force evaluated potential risks based on conservative dispersion modeling of historical OB using "worst-case assumptions [i.e, M6 propellant (no longer open burned at Camp Edward)]. This propellant was selected because it contains the highest percentage of 2,4-dinitrotoluene. Results of this modeling effort showed that the risk of cancer following 70 years of exposure to the modeled maximum concentration of 2,4-dinitrotoluene was over a million times less than one in a million cancer cases ($<10^{-12}$). The focus of this study was on the 2,4-dinitrotoluene because this component of

some types of propellant is classified as a possible carcinogen, and is the only component that may be carcinogenic. Based on these modeling results, the task force concluded (May 1991) that it was very unlikely that individuals residing near the MMR and exposed to emissions resulting from OB of propellants at Camp Edwards, would experience any significant adverse health effects due to these airborne contaminants (reference 2).

1.1.2.4. The U.S. Environmental Protection Agency (EPA) Region I and the Massachusetts Department of Environmental Protection (DEP) recommended on-site monitoring and sampling strategies aimed at meeting the citizen concerns on OB activities at Camp Edwards. A meeting was held in September 1991 (reference 3) at Camp Curtis Guild, Massachusetts. This working meeting comprised of representatives from USAEHA, Massachusetts National Guard (MNG), EPA Region I, and Massachusetts DEP discussed sampling strategies aimed at meeting the needs of the citizens groups concerned about OB activities at Camp Edwards.

1.1.2.5. In January 1992, Boston University [under contract to the Massachusetts Department of Public Health (DPH)] issued an epidemiologic study addressing the increased incidence of cancer in the upper Cape Cod area (reference 4). This study identified the OB of propellants at Camp Edwards as one of several environmental exposures on upper Cape Cod which could potentially contribute to cancer incidence. Based on a review of this document, the Agency for Toxic Substances and Diseases Registry recommended that on-site air sampling be conducted at Camp Edwards (reference 5).

1.1.2.6. The OB of artillery propellants containing 2,4-dinitrotoluene at Camp Edwards was ceased in March 1992 pending the development of an air monitoring plan. The MNG has stated that no burning of artillery propellants will resume until sampling results have been analyzed and reported to the public.

1.1.2.7. Work began on an air monitoring plan in April 1991. A draft monitoring plan was developed by USAEHA in February 1992 (reference 6) and provided to the EPA Region I and the Massachusetts DEP for review and comment. Comments were received in March 1992 (references 7 and 8). A working meeting was held in March 1992 to discuss these comments. Attending this meeting were representatives from USAEHA (to include engineers, an occupational health physician, a toxicologist, and a risk assessor), MNG, EPA Region I, Massachusetts DEP, and Massachusetts DPH. An agreement was reached regarding the strategy for ambient air sampling during the OB of propellants at Camp Edwards.

1.1.2.8. Following this meeting, a conference call was conducted between USAEHA and EPA Region I regarding specific media/analytical methods to be used for the target analytes. In April 1992, supplemental information describing USAEHA's experience using a specific media (XAD-2™ resin) for the capture of 2,4-dinitrotoluene and 2,6-dinitrotoluene was provided to EPA Region I and the Massachusetts DEP for their review (reference 9). Comments were received in May 1992 (reference 10) and were incorporated into a revised monitoring plan (June 1992) (reference 11).

1.1.2.9. Comments on the revised monitoring plan were received from the EPA Region I (reference 12), Massachusetts DEP (reference 13), and Massachusetts DPH (reference 14). An additional conference call was conducted between USAEHA and EPA Region I to clarify analytical issues.

1.1.2.10. In June 1992, the Massachusetts DEP and DPH jointly issued an information paper (reference 15) summarizing the USAEHA air monitoring plan, interpretation of results, and determination of public health implications. This information paper was disseminated to the general public, and a public meeting was conducted on 5 August 1992 in Bourne, Massachusetts to further inform the public.

1.1.2.11. Despite information presented by the MNG, DEP, and DPH at the public meeting, many local residents expressed concerns about potential exposures during the test burn. Therefore, the MNG agreed to conduct the test burn at a location other than Camp Edwards.

1.1.2.12. Based on comments received at the public meeting, it became apparent that the scope and objective of test burn needed to be reviewed. The original project scope and objective related to conducting a field demonstration designed to empirically evaluate emissions/air quality impacts associated with propellant burning at Camp Edwards. Based on input from outside commentators, concerned citizens, and other agencies, this original scope was revised. The revised project scope focused on a health risk assessment approach (i.e., air pathway analysis) to characterize air quality impacts associated with propellant burning at Camp Edwards. Once the decision was made to perform the test burn at a location other than Camp Edwards, the use of a controlled test facility to generate reliable, reproducible emission rates for target pollutants was reconsidered.

1.1.2.13. Although there were disadvantages to moving the proposed on-site (Camp Edwards) field test to a controlled test facility (including the amount that could be burned in the facility, matching test conditions with actual field conditions, and the option of

tracking the plume to downwind positions), these disadvantages were balanced against the possibility of generating reliable, reproducible emission rates for target pollutants under controlled conditions. Weighing the relative disadvantages against the relative advantages, use of a controlled test facility became an attractive alternative.

1.1.2.14. To accomplish the study objectives, the alternate test burn site selected was the BangBox (BB) Facility at the U.S. Army Dugway Proving Ground (DPG), Dugway, Utah. This type of facility was utilized during two test series conducted during the U.S. Army Armament, Munitions, and Chemical Command's (AMCCOM's) Open Burning/Open Detonation Thermal Treatment Emission Study (reference 16). The DPG BB Facility has also been used to characterize emissions resulting from the thermal treatment of several U.S. Air Force explosive munitions (reference 29). The DPG BB facility was designed based on a bang box facility located at Sandia National Laboratories (SNL) located in Albuquerque, New Mexico. The SNL bang box facility was used during the AMCCOM study to determine gaseous and particulate products from small-scale explosive detonations and propellant burns (reference 16-17)

1.1.2.15. A revised air sampling plan (February 1993) was prepared associated with the burning of Camp Edwards propellants in the DPG BangBox Facility (reference 18). The revised sampling plan was reviewed by the Massachusetts DEP technical staff and approval was recommended. The test burns were conducted in the BB Facility during the period 16-18 March 1993. This report summarizes the results of the DPG test.

1.1.2.16. The results of both the USAEHA and the DPG sampling effort will undergo technical review by the Massachusetts DEP, Massachusetts DPH, and EPA Region I. Validated data from the test burns in the DPG BB Facility will be used as the input for emissions data for follow-up modelling using site-specific Camp Edwards meteorological data.

1.1.3. Thermal Treatment Considerations

Despite their obvious advantages, OB thermal treatment disposal operations cannot be conducted freely anywhere in the United States. Regulators, as part of the Resource Conservation and Recovery Act permitting process, are now looking for accurate scientifically-obtained data to support all permit applications and, without these data, may both deny permits and close existing OB operations. Some OB disposal operational sites have already been closed for this reason.

Recognizing the sensitivity of the issue, the MNG determined to obtain data on emissions produced by OB the unwanted propellants it typically accumulates. The MNG, in adopting the position that empirical emissions data obtained using the best technologies available is vastly preferable to model-generated emissions data, decided to fund sophisticated testing using the only system which has been audited and recognized by environmental agencies (reference 16 and 17).

1.2. THE DUGWAY PROVING GROUND - WASTE CHARACTERIZATION TESTING SYSTEM

1.2.1. Development

In 1982, the US Army anticipated environmental restrictions on OB/OD operations and embarked on a program to develop a testing system capable of satisfying existing and anticipated data needs. The OBOD thermal treatment emissions study, conducted by the U.S. Army Armament, Munitions and Chemical Command (AMCCOM)¹, was the most significant part of the development effort which successfully achieved its goal. The OB/OD testing system, developed and validated during the study, embraces a unique testing facility, specialized instruments, equipment, and procedures, and individual skills exercised by recognized authorities in their fields. Regulatory and research elements of the USEPA at the national and regional level participated in the study, thus ensuring that USEPA considerations were satisfactorily integrated into the testing system.

1.2.2. Objectives

The OB/OD testing system has several prime objectives. The first is to identify specific items that are viable candidates for open-air thermal-treatment destruction. Research and development funds can then be focused towards developing alternative disposal technologies for those munitions found unsuitable for OB/OD procedures. The second objective is to provide emissions data for supporting the permitting process.

¹Two series of tests were conducted during the Open Burning/Open Detonation Thermal Treatment Emission Study. These are reported in the BangBox Test Series Final Report (reference 16) and Field Test A, B, and C Final Report (reference 17).

1.2.3. Application to MNG Needs

The MNG, faced with accumulating stocks of propellants which require disposal at Camp Edwards, provided funds to conduct a testing program which would be oriented to its permitting-data needs and would use the OB/OD testing system. Based on extensive discussions with MNG environmental officers, this test was designed to meet data needs peculiar to the Camp Edwards' situation, e.g., replication of temperature and relative humidity conditions normal during the periods when OB is conducted on the installation. Representatives from the MNG and Massachusetts environmental and public health agencies made on-site visits to DPG, to observe testing and discuss technical issues with the DPG project officer who developed the testing system and was responsible for conducting the MNG test. Also present during testing, and conducting parallel sampling of propellant emissions, were representatives from the USAEHA. As a consequence, the test and subsequent analytical efforts are expected to provide the scientific data required by the MNG and desired by the concerned communities.

1.3. MULTIDEPARTMENTAL INVOLVEMENT

The DPG project officer has maintained continuous communication with MNG, and the USEPA Atmospheric Research and Exposure Assessment Laboratory (AREAL). Adjustments made to the test design plan, letters of instruction (LOIs), assay procedures, and data analysis techniques as the test process unfolded, reflect the recommendations of these organizations.

SECTION 2 SCOPE

2.1 OBJECTIVES

This test had three objectives:

- a. To establish and implement a test program in a controlled facility to quantitatively measure air pollutants which may potentially be released as a result of burning M3/green bag artillery and M9 mortar propellants.
- b. To sample and characterize emissions produced by open burning of M3/green bag artillery and M9 mortar propellants in a controlled facility (DPG BB) which approximates field conditions at Camp Edwards, Massachusetts.
- c. To generate reliable and verifiable emission factors (dispersion model input emission rates) for target pollutants associated with the burning of M3/green bag artillery and M9 mortar propellants.

2.2 TEST ORGANIZATION

2.2.1 U.S. Army Dugway Proving Ground

The Munitions and Obscurants Branch, Materiel Test Directorate (MTD), DPG, held organizational responsibility for this test. Within this framework, the OB/OD project officer (who developed the testing system) exercised overall direction and control. Technical and operational support was provided by numerous agencies within MTD, e.g., the Instrumentation Division was responsible for the continuous monitoring of criteria gases and high-volume (hi-vol) sampler flow.

2.2.2 Technical Steering Committee (TSC)

The TSC which provided technical guidance throughout development of the OB/OD testing system, actively participated in all phases of this testing program. Many members of the TSC were on-site during the entire test, with the remaining members joining the group when required.

2.2.3 U.S. Environmental Protection Agency

The USEPA AREAL, Research Triangle Park, North Carolina, provided sampling and laboratory assay advice to the DPG project officer. Additionally, AREAL maintained quality assurance (QA) support during testing and assay phases, and prepared the quality assurance/quality control (QA/QC) narrative for this report.

2.2.4 Alpine West Laboratories (AWL)

Alpine West Laboratories, Provo, Utah, was responsible for sampling and assay of semivolatile organic compounds (SVOC) collected on Whatman high-purity quartz microfiber filters (20.3- x 25.4-cm) using hi-vol samplers. The AWL director developed supercritical fluid chromatograph/mass spectrometer (SFC/MS) methodology for application to energetic materials, which was extensively used in assaying SVOCs during development of the OB/OD testing system and throughout this test.

2.2.5 U.S. Army Environmental Hygiene Agency

2.2.5.1 The USAEHA provided initial coordination between the MNG and DPG and prepared the test design plan. During test execution, USAEHA personnel were on-site to conduct sampling in addition to that sampling conducted by DPG and its contractors. Following the OB testing, USAEHA analyzed its samples and prepared a separate report.

2.2.5.2 The results of both the USAEHA and the DPG sampling effort will undergo technical review by the Massachusetts DEP, Massachusetts DPH, and EPA Region I. Validated data from the test burns in the DPG BangBox Facility will be used as the input for emissions data for follow-up modelling using site-specific Camp Edwards meteorological data.

2.2.6 Oregon Graduate Institute of Science and Technology (OGI)

The OGI, Beaverton, Oregon, was responsible for sampling and assay of volatile organic compounds (VOC). The laboratory director, who participated in development of the OB/OD testing system and who maintains an active sampling program for the USEPA and many foreign governments, captured emissions in proprietary canisters and conducted assays using TO-12 and TO-14 procedures.

2.2.7 Radian Corporation

Radian Corporation, Research Triangle Park, North Carolina, provided additional sampling and assay support for SVOCs. Radian sampled with PS-1 samplers using XAD-2™ resin. It has participated in TSC meetings for this and other recent testing programs which employed the OB/OD testing system.

2.2.8 Andrulis Research Corporation

The Salt Lake City, Utah, office of Andrulis Research Corporation was an active participant in the planning, statistical analysis, and reporting phases of this test.

2.3 TEST MATRIX

2.3.1 General

Six trials were conducted during this test to produce the required data. Background samples were taken on a daily basis

2.3.2 Matrix

The test matrix presented in Table 2.1 on this page provides a synopsis of the testing activities. Section 3 of this report provides detailed descriptions of each tested item, and how the items were prepared for testing. As the matrix suggests, the test progressed on schedule and without interruption. Two trials plus background sampling were achieved each day; technical personnel were made available on a priority basis when their skills were needed, and the TSC remained on-site to provide immediate response when technical issues needed prompt resolution.

Table 2.1 Test Matrix for Testing of Energetic Materials for the Massachusetts Army National Guard.

Date (1993)	Time (local)	Propellant	Propellant Weight (g)	Donor Charge ^a (g)	Temp ^b	RH ^c
16 March	1516	M9 ^d	2400 ^e	4	A	A
16 March	1738	M1 ^f	2156 ^g	4	A	A
17 March	1357	M1	2156	4	H	H
17 March	1605	M1	2156	4	A	A
18 March	0830	M1	2156	4	C	H
18 March	1235	M1	2156	4	A	A

^aA donor charge of Hercules UniqueTM smokeless powder assisted propellant ignition.

^bTemperature. Temperature classifications are: A - ambient, C - cold, H - hot.

^cRelative humidity. Humidity classifications are: A - ambient, H - high.

^dM9 propellant, used to fire mortar cartridges, was tested with the bags in which it is normally contained for firing. A total of 232 bags of propellant were burned during this trial.

^ePropellant was packaged in 232 bags, each containing less than 11 g of propellant. Total weight of the empty bags was approximately 270 g.

^fM1 propellant, used to fire artillery projectiles, was tested in the bags in which it is normally contained for firing and with the flash reducer with which it is usually combined. It is designated as M3/Green Bag when in this configuration.

^gTwo M3/green bags charge No. 4 and two M3/green bags charge No 5 were burned per trial. Weight shown is for total M1 propellant only. The total weight of flash reducer was 113 g; the four empty bags totaled 69 g.

SECTION 3. SPECIFICATIONS

3.1. Test Facility

All trials supporting this program were conducted in the Propellant, Explosive, and Pyrotechnic Thermal Treatment Evaluation and Test facility (PEP-TTET), better known as the BangBox (BB). Located in the West Area of DPG, the BB was constructed according to an advanced design and equipped with state-of-the-art instruments and samplers. The BB is operated according to the procedures developed and refined during the past extensive AMCCOM OB/OD studies.

3.1.1. BangBox

3.1.1.1. Site. The BB site, in an isolated section of DPG's testing complex, offers specific advantages for environmentally-related testing. The absence of any nearby testing precludes adulteration of the sampling process with emissions produced by unrelated testing or other activities. This a critical consideration because of the sensitivity of both *in situ* instruments used during testing and off-site laboratory instruments subsequently used in assays of samples collected at the test site. Background sampling conducted immediately prior to testing is used to identify any indigenous ambient contaminants which may be present. The 115/220-V electric service to the site ensures that uninterrupted stable power is available for BB and its instrumentation.

3.1.1.2. Chamber The test chamber is a 15.2-m (50-ft) diameter hemisphere constructed of plasticized fabric anchored onto a concrete pad. The chamber's nominal 1000-m³ (35,300-ft³) volume holds substantially more than sufficient air for complete combustion of small propellant and explosive charges, thus emulating actual open-air destruction operational conditions. Within the chamber are an array of samplers, a 1-m³ (35.3-ft³) detonation pit for explosive materials, and a series of shields to prevent shrapnel from reaching and damaging the walls during tests of explosives, and flame from scorching the walls during burn tests. Environmental control is accomplished with electric heaters to raise temperatures during winter tests, and evaporators to raise humidity levels. An automatically-controlled blower provides filtered air to keep the chamber inflated at a constant overpressure without introducing dust. Figure 3.1 displays a schematic diagram of the chamber as configured for this test.

3.1.1.3. Airlock. An adjoining airlock serves multiple purposes, including ready access to the chamber through an ordinary-size door for personnel and garage-style door for equipment, a controlled-environment area for rack-mounted real-time instruments and data recorders, a small sheltered area for personnel involved in test preparation, and a telephone connected to the DPG switchboard. An air-conditioner/ heater operates continuously to assist in maintaining instrument stability and eliminating exterior airborne dust from being drawn into the airlock. Figure 3.2 displays a schematic diagram of the airlock as configured for this test.

3.1.1.4. Command post (CP). The CP, approximately 560 m (1700 ft) from the BB, contains control equipment to complete the testing once explosive ordnance specialists have prepared the test material for detonation and returned. Personnel in the CP have an unobstructed view of the BB and surrounding terrain (except for a very small area directly behind the chamber), and can observe the chamber's interior by means of a television monitor. The remotely initiated firing circuit terminates in a locked box in the CP accessible only to test firing personnel. Telephones and two-way radios provide communication. Qualified project personnel staff the CP during all testing.

3.1.1.5. Instrument van. The instrument van, next to the CP, contains video recorders connected to the camera in the BB chamber, additional communications equipment, and repair parts and manuals for real-time criteria gas analyzers and hi-vol samplers. At least one instrument specialist occupies the van while testing is underway.

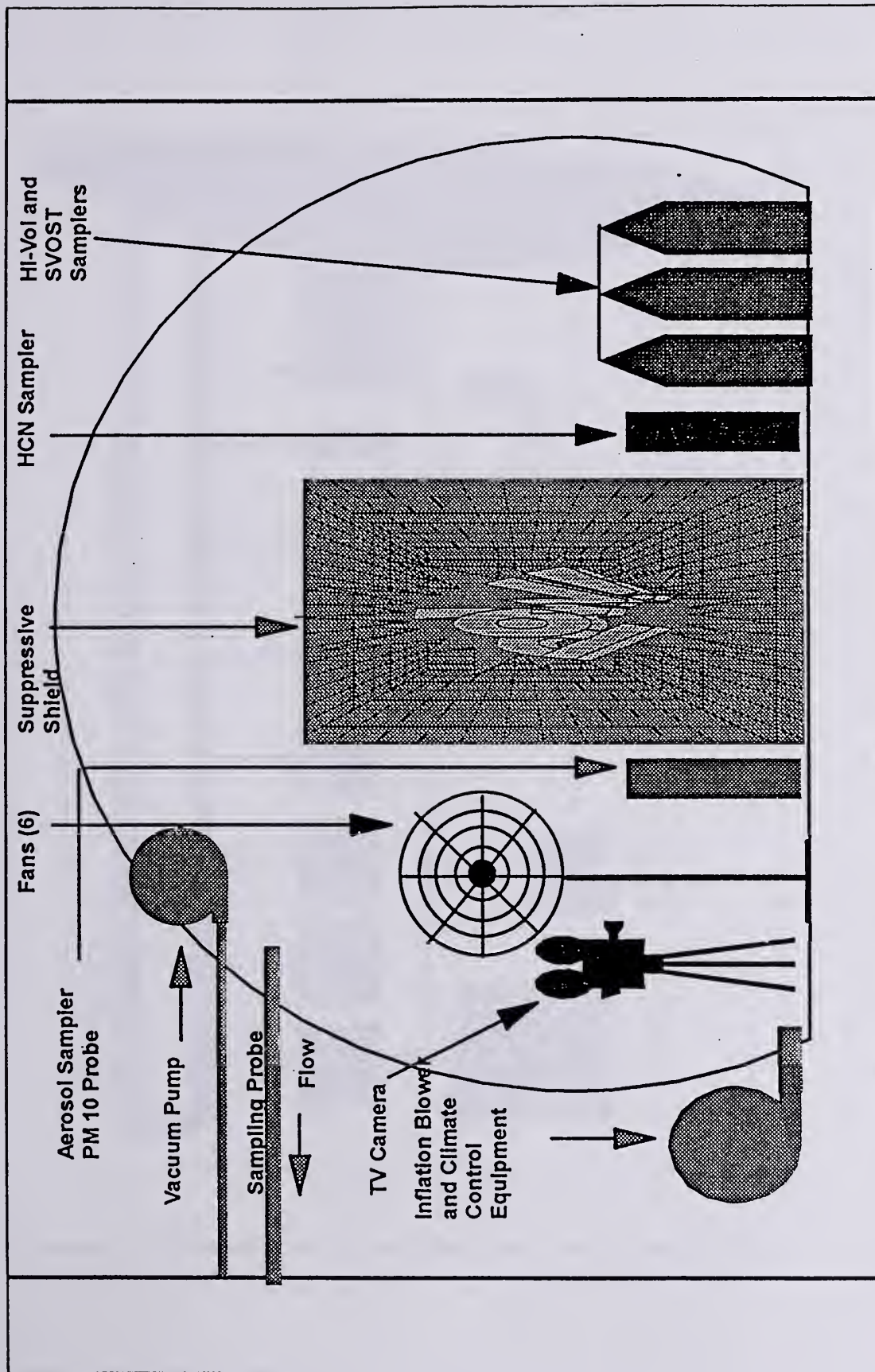


Figure 3.1 Schematic Diagram of the BangBox Test Chamber as Outfitted During Energetic Materials Emissions Testing for the Massachusetts National Guard.

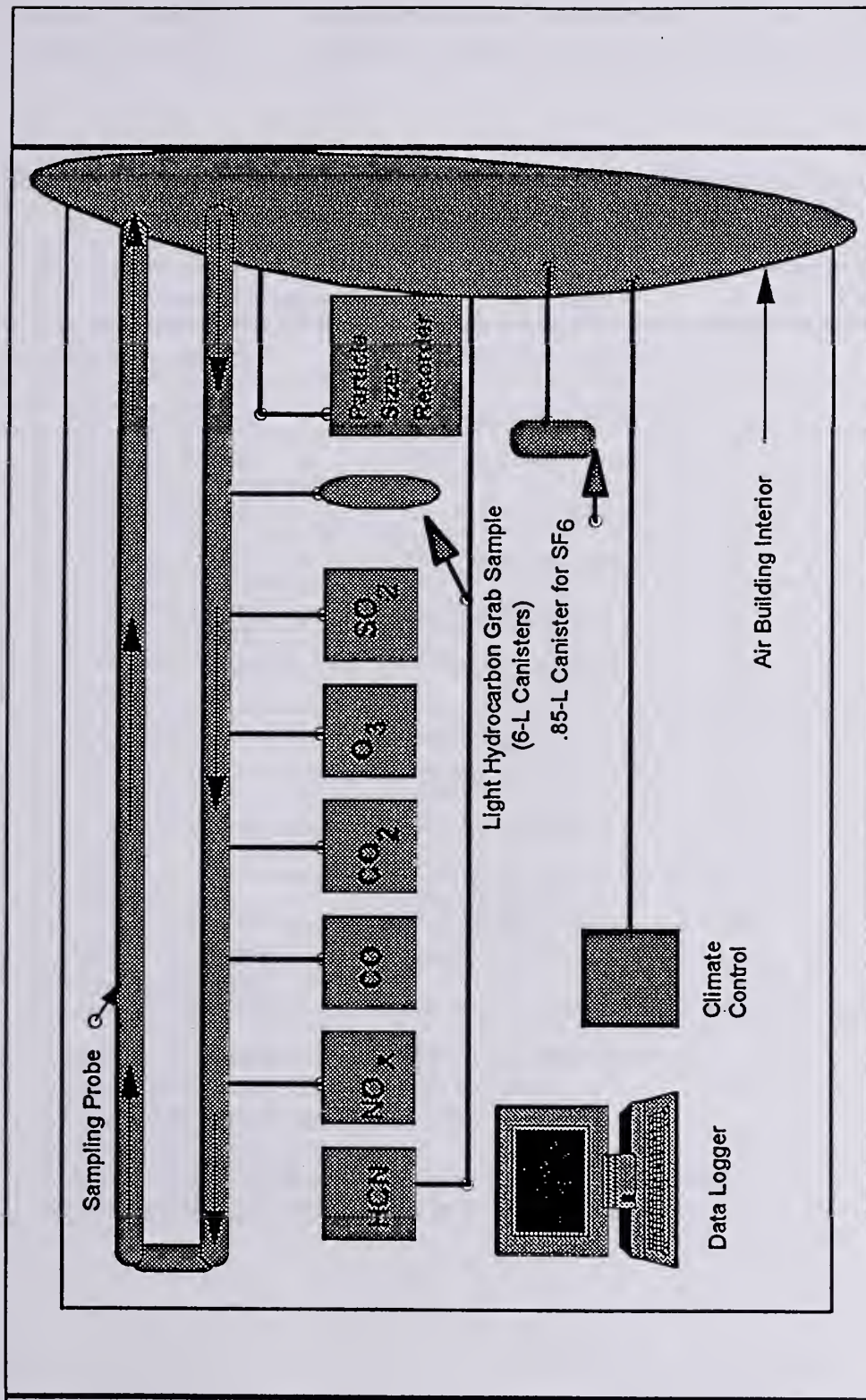


Figure 3.2 Schematic Diagram of the BangBox Airlock as Outfitted During Energetic Materials Emissions Testing for the Massachusetts National Guard.

3.1.1.6. Instruments. Major instruments and samplers used during this test are presented in Table 3.1. These instruments were calibrated using DPG procedures.

Table 3.1 Major Instruments and Samplers Used During Energetic Materials Emissions Testing for the Massachusetts National Guard.

Instrument/Sampler	Purpose	Number	Location
TECO model 48	CO real-time analysis	1	airlock ^a
TECO model 41H	CO ₂ real-time analysis	1	airlock ^a
TECO model 42	NO _x real-time analysis	1	airlock ^a
TECO model 49	O ₃ real-time analysis	1	airlock ^a
TECO model 43	SO ₂ real-time analysis	1	airlock ^a
MSA model 7200	HCN analysis	1	airlock ^a
SemiVOST ^c w/pump and flowmeter (PS-1)	SVOC ^d sampling	3	chamber
High-volume pump/manifold assembly	SVOC, metals, carbon sampling	3	chamber
6-L stainless-steel (SS) canister	VOC ^e sampling	1	airlock ^a
0.85-L canister	SF ₆ ^f sampling	1	airlock ^a
486-DX computer w/Bernoulli drive	data logging	1	airlock

^aChamber atmosphere sampled through transport tube.

^bControl unit in airlock, sensor in chamber.

^cSemivolatile organic sampling train.

^dSemivolatile organic compound.

^eVolatile organic compound sampled with 6-L SS canister.

^fSulfur hexafluoride sampled with 0.85-L SS canister.

3.1.1.6.1. Continuous atmospheric sampling of the BB facility's internal atmosphere (before and after burns) was conducted via a sampling manifold located in the airlock. The various instruments were located both in the airlock and in the test chamber (see Figures 3.1 and 3.2 on pages 3-4 and 3-5), and were running continuously.

3.1.1.6.2. Particulate matter less than 10 (μ) (PM_{10}) was continuously monitored. The instrument is an EPA equivalent method for PM_{10} (EPA EQPM-1090-079) and was located in the test chamber. The continuous read-out was located in the airlock.

3.1.1.6.3. A series of 6-liter SUMMATM canisters were used in parallel in the airlock to sample for volatile organic compounds (VOCs).

3.1.1.6.4. A series of 0.85-L SUMMATM canisters were used to sample for the tracer gas sulfur hexafluoride (SF_6) released during the burning trials. This data was used; to monitor air transport within the test chamber, to calculate the total volume of the test chamber, and to calculate the air exchange in the test chamber.

3.1.1.6.5. Semivolatile organic compounds (SVOCs) were sampled using two different methods; (1) PS-1 samplers using XAD-2TM resin, and (2) high volume samplers using quartz fiber filters.

3.1.1.6.6. A portion of the quartz fiber filter from the high volume samplers was used to detect metals.

3.1.1.6.7. Process parameters (e.g. barometric pressure, dome pressure, humidity, temperature, and propellant ignition time) were monitored continuously using the Labtech NotebookTM software program installed on the data-logger.

3.1.2. Letters of Instruction

Project personnel prepared LOIs which defined the procedures which were used during preparation, execution, and analyses phases of the test. These LOI are contained in appendix C to this report.

3.1.3. Test Items

3.1.3.1. Propellant Classifications

There are three primary categories of propellants; single-based, double-based, and triple-based. Single-based propellants are composed primarily of nitrocellulose, double-based propellants are composed primarily of nitrocellulose and nitroglycerin, and triple-based propellants are composed primarily of nitrocellulose, nitroglycerin, and nitroguanidine. Triple based propellants are not used at Camp Edwards and were not used in this test.

3.1.3.2. Propellant Charges Open Burned at Camp Edwards

3.1.3.2.1. The single-based 155-mm propellant charge containing M1 propellant (M-3/green bag).

3.1.3.2.2. The double-based 4.2-inch mortar (M36A2) containing M8 and M9 propellants, the double-based 81-mm mortars (M90 and M90A1) containing M9 propellant, and the double-based 60-mm high explosive round (M181) containing M-8 propellant.

3.1.3.3. The DPG BangBox Test Facility

Two types of artillery propellants were provided by the MNG for testing.

a. M3/Green Bag Propellant.

M1 propellant, a single-based propellant, is used for projecting artillery projectiles from artillery pieces such as the 155-mm howitzer. The M1 propellant provided for testing was configured as M3/green bag charges No. 4 and No.5, both of which include a flash reducer; charge No 5 bags contain more propellant than do charge No. 4 bags. The M3/green bags are loaded into the artillery tube behind the projectile. Table 3.2 presents the nominal composition of this propellant.

b. M9 Propellant

M9 propellant, a double-based propellant, is used for projecting 4.2-in and 81-mm mortar cartridges. The propellant provided for testing was configured as small bags which are attached to the rear of the mortar cartridge for firing. Table 3.3 presents the nominal composition of this propellant.

Table 3.2 Nominal composition of M3/Green Bag Propellant Tested During Energetic Materials Testing.

Compound	Percentage of Total Weight
Dibutylphthalate	4.90
Dinitrotoluene	9.90
Diphenylamine	1.00
Nitrocellulose	84.20

Table 3.3 Nominal Composition of M9 Propellant Tested During Energetic Materials Testing.

Compound	Percentage of Total Weight
Diphenylamine	0.75
Nitrocellulose	57.75
Nitroglycerin	40.00
Potassium nitrate	1.50

3.1.4. Preparation of Propellants for Testing

3.1.4.1. M3/green bag charges No 4 and No 5 propellant.

A total of four M3/green bags of propellant (2 #4 bags & 2 #5 bags, including the bags) were burned in each M1 propellant trial. Prior to the first M1 burn, munitions specialists obtained weights of the M1 propellant, flash reducer, and bag for one charge No 4 and one charge no 5; bags of M1 propellant for following burns were weighed individually, but *in toto* without separating contents and bag. For each M1 burn trial, two M3/green bag charge No 4 and two M3/green bag charge No 5 were combined in a stainless-steel burn pan (Figure 3.3). Two electric squibs and 4 oz of Hercules Unique™ smokeless powder ignited the contents of the pan.

3.1.4.2. M9 propellant.

The M9 propellant came in small bags. Each bag, containing approximately 10.5 g of propellant, weighed slightly less than 12 g. Technicians loaded 232 unopened bags of propellant into stainless-steel burn pans and used 4 g of Hercules Unique™ smokeless powder and two electric squibs to ignite the charge (Figure 3.4).



Figure 3.3 Configuration of M3/Green Bag Propellant Charges Used During the Energetic Materials Testing Conducted for MANG.



Figure 3.4 Configuration of the M9 Charge During Energetic Materials Testing Conducted for MANG.

3.1.5. Target Analytes (See Appendix C-10 for Complete List)

The target analytes presented in the following three tables were nominated by the TSC, based upon its prior experience with energetic materials and known permitting needs of the MNG. The DPG project officer approved the TSC recommendation. As initial assay results were received, the TSC recommended that some changes be made to this list.

Table 3.4 Gases and Volatile Organic Compounds Targeted for Analysis During Energetic Material Emissions Testing.

Target Analyte	Test Material	
	M-1	M-9
Gases		
CO	X	X
CO ₂	X	X
O ₃	X	X
SO ₂	X	X
NO _x (NO, NO ₂)	X	X
Volatile Organic Compounds (VOC) (See Table 3.5)		
Methane	X	X
GC-FID C ₂ - C ₁₂ hydrocarbons GC-MS C ₂ - C ₁₅ organics to include TO-14 ^a list	X	X
Other		
HCN	X	X
HCl	X	X
SF ₆	X	X
Carbon (elemental & organic)	X	X

^aEPA official list of air toxics determined by the TO-14 standard procedure.

Table 3.5 Categories of Volatile Organic Compounds Analyzed by OGI

Compound	Units	Compound	Units
Carbon dioxide	ppmv	Olefins - Cont'd	
Carbon monoxide		Isoprene	µg/m³
Methane		1,3-Butadiene	
Paraffins		trans-2-Pentene	
n-Heptane	µg/m³	cis-2-Butene	
2,4-Dimethylhexane		cis-2-Hexene	
2-Methylheptane		1-Pentene	
2-Methylpentane		2-Methyl-2-butene	
3-Methylpentane		1-Hexene	
Ethylcyclohexane		4-Methyl-1-pentene	
n-Hexane		trans-2-Butene	
i-Butane		i-Butene	
Methylcyclopentane		2-Methyl-2-pentene	
n-Butane		2-Methyl-1-butene	
2,4-Dimethylpentane		2-Pentene	
2,2-Dimethylpropane		Cyclopentene	
Cyclohexane		Non-Benzene Aromatics	
n-Pentane		Toluene	µg/m³
2,3-Dimethylpentane		3-Ethyltoluene	
Cyclopentane		1,3,5-Trimethylbenzene	
3-Methylhexane	n-Propylbenzene		
n-Octane	1-Ethyltoluene		
Ethane	Styrene		
2,3-Dimethylhexane	i-Propylbenzene		
Methylcyclohexane	2-Ethyltoluene		
2,3,4-Trimethylpentane	Ethylbenzene		
n-Nonane	o-Xylene		
2,3-Dimethylbutane	p-Xylene		
2,2,3-Trimethylpentane	m-Xylene		
i-Pentane	1,2,4-Trimethylbenzene & sec-Butylbenzene		
Propane	Acetylene	µg/m³	
2,2-Dimethylbutane	Benzene	µg/m³	
3-Ethylhexane	Terpenes		
Olefins	µg/m³	β-Pinene	µg/m³
Ethylene		α-Terpinene	
2-Methyl-1-pentene		d-Limonene	
Propene		α-Pinene	
1-Butene		Δ³-Carene	
trans-2-Hexene		γ-Terpinene	
3-Methyl-1-butene		Terpinolene	
Mycrene			

Table 3.6 Semivolatile Organic Compounds Targeted for Analysis During Energetic Material Emissions Testing by SFC/MS Analysis.

Target Analyte	Test Material	
	M-1	M-9
Semivolatile Organic Compounds		
2,4-Dinitrotoluene	X	X
2,6-Dinitrotoluene	X	X
2,4,6-Trinitrotoluene	X	X
2-Nitronaphthalene	X	X
N-Nitrosodiphenylamine	X	X
1,3,5-Trinitrobenzene	X	X
2-Nitrodiphenylamine	X	X
1-Nitropyrene	X	X
Naphthalene	X	X
Benz[a]anthracene	X	X
Benzo[a]pyrene	X	X
Pyrene	X	X
Phenol	X	X
Dibenzofuran	X	X
Diphenylamine	X	X
RDX Cyclonite ^d		X
HMX Octogen ^e		X
Tetryl		
Nitroglycerin		X
9-Phenylanthracene ^f (negative ion internal std)	X	X
1-Nitronaphthalene-d ₇ ^f (positive ion internal std)	X	X

Table 3.7 Supplemental Semivolatile Organic Compounds Target for Analysis During Testing of Energetic Materials by GCMS EPA method 8270.

COMPOUND	COMPOUND	COMPOUND
1,2,4,5-Tetrachlorobenzene	4-Chloroaniline	Fluorene
1,2,4-Trichlorobenzene	4-Chlorophenyl phenyl ether	Hexachlorobenzene
1,2-Dichlorobenzene	4-Chloro-3-methylphenol	Hexachlorobutadiene
1,2-Diphenylhydrazine	4-Nitroaniline	Hexachlorocyclopentadiene
1,3,5-Trinitrobenzene	4-Nitrophenol	Hexachloroethane
1,3-Dichlorobenzene	4-Nitroquinoline-1-oxide	Hexachloropropene
1,3-Dinitrobenzene	5-Nitro-o-toluidine	Indeno (1,2,3-cd) pyrene
1,3-Dichlorobenzene	7,12-dimethylbenz(a)anthracene	Isodrin
1,4-Naphthoquinone	Acenaphthene	Isophorone
1,4-Pheeylenediamine	Acenaphthylene	Isosafrole
1-Naphthylamine	Acetophenone	Methapyrilene
2,3,4,5- or 2,3,4,6-TCPhenol	Aniline	Methyl methanesulfonate
2,3,5,6-Tetrachlorophenol	Anthracene	Naphthalene
2,4,5-Trichlorophenol	Benzo (a) anthracene	Nitrobenzene
2,4,6-Trichlorophenol	Benzo (a) pyrene	N,N-Dimethyl-1-phenethylamine
2,4-Dichlorophenol	Benzo (b) fluoranthene	N-Nitrosodiethylamine
2,4-Dimethylphenol	Benzo (ghi) perylene	N-Nitrosodimethylamine
2,4-Dinitrophenol	Benzo (k) fluoranthene	N-Nitrosodiphenylamine
2,4-Dinitrotoluene	Benzoic Acid	N-Nitrosodi-n-butylamine
2,6-Dichlorophenol	Benzyl alcohol	N-Nitrosodi-n-propylamine
2,6-Dinitrotoluene	bis (2-Chloroethoxy) methane	N-Nitrosomethylethylamine
2-Acetylaminofluorene	bis (2-Chloroethyl) ether	N-Nitrosomorpholine
2-Chloronaphthalene	bis (2-Chloroisopropyl) ether	N-Nitrosopiperidine
2-Chlorophenol	bis (2-Ethylhexyl) phthalate	N-Nitrosopyrrolidine
2-Methylnaphthalene	Butyl benzyl phthalate	O,O,O-triethylphosphorothioate
2-Methylphenol	Carbazole	o-Toluidine
2-Naphthylamine	Chlorobenzilate	Pentachlorobenzene
2-Nitroaniline	Chrysene	Pentachloroethane
2-Nitrophenol	Diallate (cis)	Pentachloronitrobenzene
2-Picoline	Diallate (trans)	Pentachlorophenol
3,3'-Dichlorobenzidine	Dibenz (a,h) anthracene	Phenacetin
3,3'-Dimethylbenzidine	Dibenzofuran	Phenanthrene
4-Methylphenol	Diethyl phthalate	Phenol
3-Chloropropionitrile	Dimethoate	Pronamide
3-Methylcholanthrene	Dimethyl phthalate	Pyrene
3-Nitroaniline	Diphenylamine	Pyridine
4,4'-Methylene-bis-2-chloraniline	Di-n-butyl phthalate	p-(dimethylamino)azobenzene
4,6-Dinitro-2-methylphenol	Di-n-octyl phthalate	Safrole
4-Aminobiphenyl	Ethyl methanesulfonate	Tetraethyl dithiopyrophosphate
4-Bromophenyl phenyl ether	Fluoranthene	Thionazin

Table 3.8 Metals Targeted for Analysis During Energetic Material Emissions Testing.

Target Analyte	Test Material	
	M1	M9
Aluminium (Al)	X	X
Arsenic (As)	X	X
Barium (Ba)	X	X
Calcium (Ca)	X	X
Cadmiun (Cd)	X	X
Chromium (Cr)	X	X
Copper (Cu)	X	X
Murcury (Hg)	X	X
Potassium (K)	X	X
Sodium (Na)	X	X
Nickel (Ni)	X	X
Lead (Pb)	X	X
Antimony (Sb)	X	X
Tin (Ti)	X	X
Zinc (Zn)	X	X

SECTION 4. DATA COLLECTION, ANALYSES, AND RESULTS

4.1. GENERAL METHOD

4.1.1. BangBox Characterization

4.1.1.1. Objectives

- a. To determine the BB dilution rate under OB/OD operating conditions.
- b. To determine the volume of the BB.

4.1.1.2. Test Procedure

4.1.1.2.1. Data Required

- a. The amount of sulfur hexafluoride (SF_6) tracer released into the BB chamber (determined from the initial volume and initial concentration of SF_6 contained in the 0.85L SUMMA™ canister).
- b. The concentrations of SF_6 as monitored at 3-min intervals from 3 minutes after detonation to approximately 30 minutes after detonation.
- c. BangBox temperature and atmospheric pressure.
- d. Pressure differential between the BB and outside atmosphere.

4.1.1.2.2. Data Acquisition Procedures

The SF_6 data were collected during all trials except the M9 trial conducted on 16 March 1993 when the release valve on the SF_6 canister failed to function. One SF_6 data point was deleted as an outlier from the M-3 burn on 16 March 1993.

- a. SF_6 Tracer. A 0.85-L canister of SF_6 gas mixed with air was placed on the floor immediately adjacent to the outside of the suppressive shield. This canister had been pressurized to approximately 10 atmospheres at OGI and contained an initial concentration of SF_6 of approximately 500 ppmv. An electric valve on the canister was connected to the detonation relay so the canister valve would open and release SF_6 into the chamber at the time of detonation..

b. SF_6 tracer sampling. The 0.85-L canisters were used to sample the interior atmosphere containing the SF_6 tracer gas. The canisters were evacuated to <50 mtorr prior to sampling and then pressurized to approximately 103 kPa (15psi) with sampled air during each trial. The contents of the 0.85-L canisters were subjected to gas chromatography (GC) with an electron capture detector (ECD) assay at OGI.

c. Pressure differential. The pressure differential between the BB chamber and the outside atmosphere was preset to maintain a differential of 1.3 in of H_2O to maintain the structural integrity of the BB. The pressure differential was recorded using Labtech-Notebook®.

d. Atmospheric pressure and BB temperature. Atmospheric pressure and BB temperature were transmitted and recorded using data-logging instrumentation and Labtech-Notebook®.

e. Propellant. The propellant materials burned are described in paragraphs 3.1.3.2.

f. Mixing fans. The mixing fans were operated continuously at the high-speed setting from before the time of initiation of burning until sampling was completed.

4.1.1.3. Analytical Procedures

4.1.1.3.1. Exponential model

The SF_6 concentration data, gathered during the sampling period after the propellant burn and after a period of mixing to establish homogenous gas concentration (usually 3 min) were used to determine the dilution rate of the BB from ventilation that occurs from the pressurization of the BB chamber interior. The SF_6 concentration data were fitted to an exponential model. The SF_6 concentration at zero time (C_0) was used in computing the BB volume.

Equation 4.1 Exponential Model Used To Determine Aerosol Dilution

$$C_t = C_0 e^{kt}$$

where C_t = concentration of the species of interest at time = t,
t = time after detonation, burn, or tracer release,
 C_0 = concentration at time = 0,
k = exponential rate of change per unit of time.

4.1.1.3.2. BB Volume

a. The SF_6 concentration data were also used to estimate the volume of the BB. The method of

estimating this value can be stated as:

Equation 4.2 BangBox Volume

$$V_{BB} = \frac{CV_{DPG}}{C_{BB}}$$

where V_{BB} = BB volume,
 C = SF_6 gas concentration in canister,
 V_{DPG} = volume of gas released from canister at DPG,
 C_{BB} = SF_6 concentration in BB at release.

b. The BB volume estimates for each trial are shown in Table 4.1. The BB volumes shown are adjusted to standard temperature and pressure (STP) (25°C and 760 torr). The average BB volume calculated from the SF_6 data was used when calculating the mass of species and EFss by the cloud volume times concentration method.

4.1.1.4. Test Findings

4.1.1.4.1. Aerosol Dilution from Ventilation

The SF_6 concentration data points (from the 0.85-L SUMMA™ canisters) and time after dissemination were used to determine a least squares fit to Equation 4.1. Estimates of the BB chamber aerosol dilution from ventilation are shown in Table 4.1. Dilution rates from ventilation ranged from -0.0201, to -0.0690, with an average of -0.0206 (1/min). The -0.069 dilution rate was not included in the average as this rate only existed during the first 15 min of trial, due to a pressure release door that had not properly seated.

4.1.1.4.2. BB Chamber Volume

The volume of the BB chamber ranged from 882 to 987 m³ with an average of 936 m³ and a standard deviation of 41.6 m³ (Table 4.1). These values are based on the SF_6 concentration values from the exponential model used in Equation 4.1. The average volume was used when calculating the mass of species and EFss (EFs) by the volume times concentration method.

Table 4.1 Aerosol Dilution Rate (k), Half-Life, and Volume of the BangBox From Least Squares Fit of SF_6 Concentration Data to an Exponential Model.

Date (1993)	Time (MST)	Test Material	Intercept (pptv)	Rate (k/min)	R^2	Half-Life (min)	Volume (m^3)
03-16	1515	M9	ND ^a	ND	ND	ND	ND
03-16	1733	M3	5158	-0.0690 ^b	0.9976	10	981
03-17	1357	M3	5733	-0.0209	0.9972	33	882
03-17	1605	M3	5590	-0.0209	0.9990	33	905
03-18 ^c	0830	M3	5324	-0.0201	0.9620	34	987
03-18	1235	M3	5481	-0.0205	0.9982	34	923
		AVERAGE					935.6
		STANDARD DEVIATION					41.64

^aNo data.

^bCounter-weights on pressure release door were not in place from start to approximately 15 min after ignition.

^cThe 6-min data point deleted as an outlier.

4.1.2. High-Vol and PS-1 Sampler Flow

4.1.2.1. Objective: To develop correction factors for the loss of flow in the hivol samplers and the PS-1 samplers.

4.1.2.2. Test Procedure

4.1.2.2.1. Data Required

Flow rates of the hivol sampler and PS-1 samplers over the period of sampling.

4.1.2.2.2. Data Acquisition Procedures

a. The hivol sampler is a continuous sampler which collects the total mass of particulate material from the volume of air that passes through the collection media. Considerable loss of flow occurred in the sampling from beginning to end of sample (usually about 30 min). Each of the hivol instruments had a flow rate monitor connected to Labtech-Notebook® software with voltages recorded at one-sec intervals. These voltages were converted to flow rates in m^3/min over the duration of sampling. As shown in Figure 4.1, the data showed a uniform flow over periods when background air was sampled and a very precipitous dropoff in flow after detonation. The total volume of air sampled was calculated by numerical integration.

b. The PS-1 sampler is a continuous sampler which collects the total mass of particulate material on the filter and volatiles in a resin bed. The flow rates were measured at the beginning of the trial and at the end of trial. A linear interpolation for flow during background and during trial sampling was used. The total volume of air sampled was calculated from the average flow rate multiplied by the time duration of sample.

4.1.2.2.3. Analytical Procedure

a. Adjustment of SF_6 data

The SF_6 concentration data for each trial was adjusted to account for the dilution effect of the reduced flow. The adjustment was accomplished using the following equation.

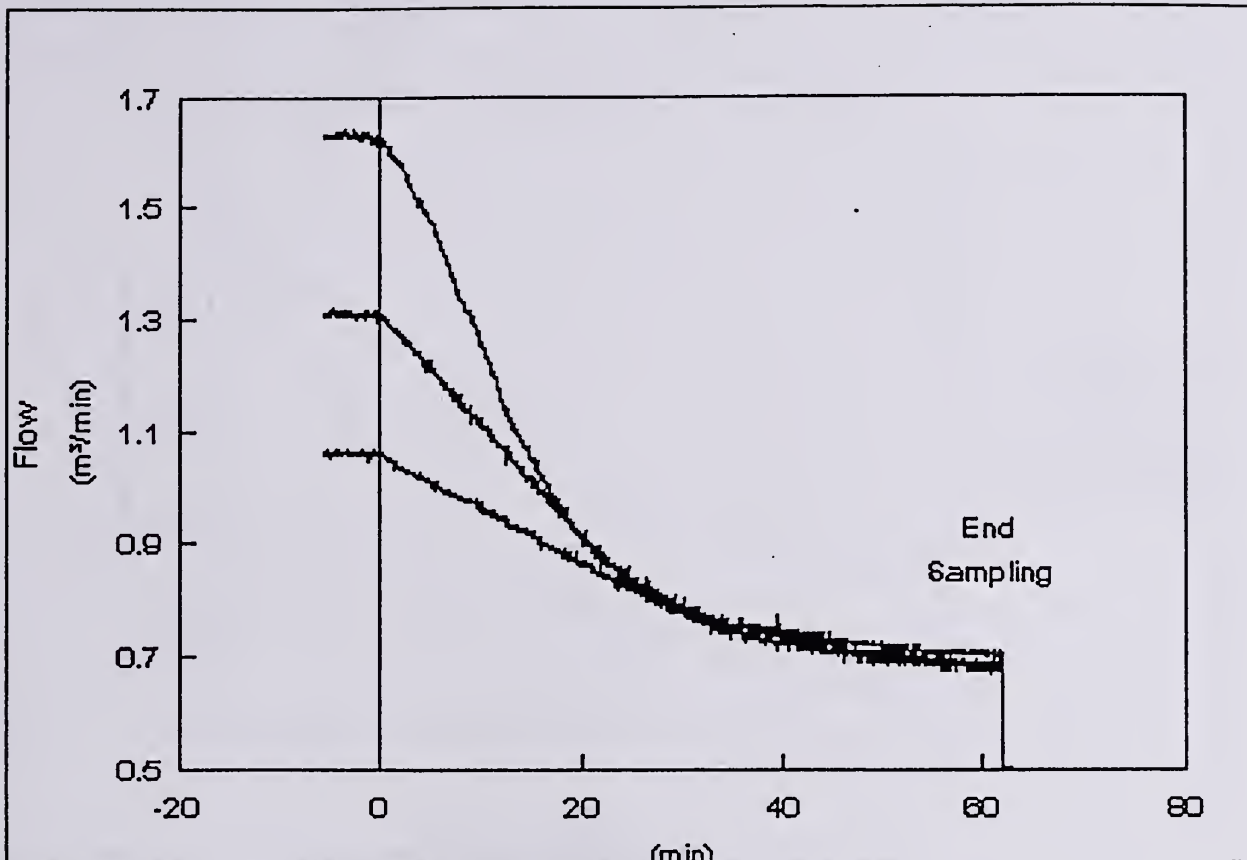


Figure 4.1 Flow Rate for the Three Hivol Samplers Used During the M9 Trial.

Equation 4.3 Flow Dilution Adjustment

$$Diluted\ SF_6\ Conc_{t_i} = \frac{FlowRate_{t_i}}{FlowRate_{t_0}} \times SF_6\ Conc_{t_i}$$

$$0 \leq \text{time } (t) \leq \text{time of end of trial}$$

b. Exponential Model

The diluted SF_6 concentration data were used to determine an exponential rate of change per unit of time, Figure 4.2. This rate of change includes dilution from BB ventilation and dilution from change in flow which occurred in the hivol sampling. This rate was used to calculate correction factors to adjust the concentration data for dilutions that occurred during the trial. As a safe sided expedient the hivol correction factor was also used for the PS-1 sample (a larger correction factor than that derived from a linear model).

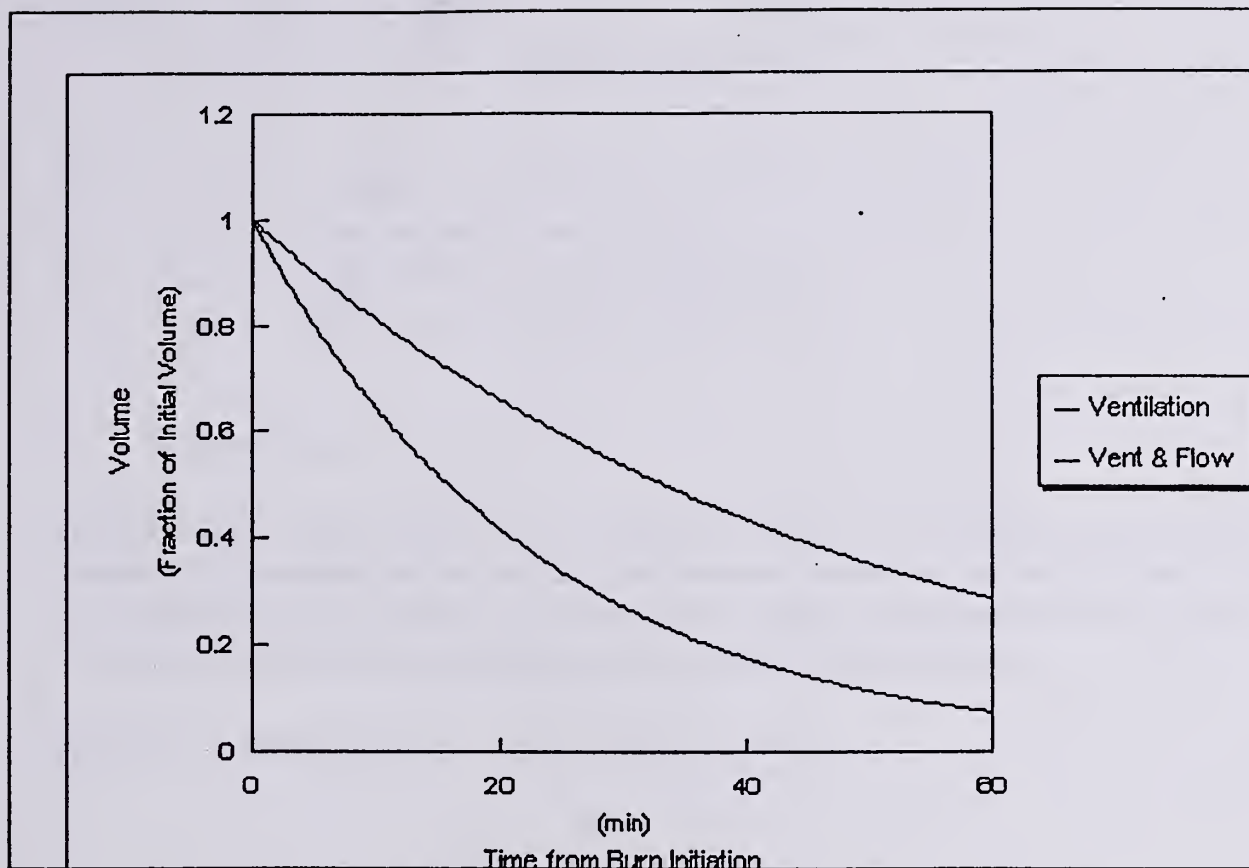


Figure 4.2 Dilution from Ventilation and Ventilation Plus Loss of Flow from Filter Loading.

4.1.3. Background Corrections

All data were adjusted for background by subtracting the concentration of the species collected as background from the mass of species collected during the collection of the test sample.

Equation 4.4 Background Correction

$$M_S = M_{TS} - (C_{BS} * V_{total})$$

where M_S = corrected mass of species
 M_{TS} = total uncorrected mass of species
 C_{BS} = concentration of species in background air
 V_{Total} = volume of air sampled by collection media

4.1.4. Emission Factors

Emission factors were calculated by the cloud volume method. This method uses the calculated concentration at completion of burn assuming the combustion products are distributed uniformly within the enclosed BB chamber. The concentrations are derived using the slope parameter from the exponential model fit of the the SF₆ data and the species dosage obtained from air sampling.

Equation 4.5 Emission Factor by Volume Times Concentration

$$EF = \frac{C_S * V_{BB}}{M_{EM}}$$

where EF = emission factor
 C_S = concentration of species
 V_{BB} = volume of BB chamber
 M_{EM} = mass of energetic material

4.2. Trial Conditions

The conditions that existed within the interior of the BangBox during the individual trials are given in Table 4.2.

4.3. M3/Green Bag Propellant Burn EFss

4.3.1. Volatile Organic Compounds

The EFss for selected volatiles and groups of volatiles compounds are shown in Table 4.3. The complete volatile-data package from the assay of the SUMMA™ canisters are included in Appendix F.

Table 4.2 Environmental Conditions Within the BangBox During the Massachusetts National Guard Trials of M3 and M9 Open Burning

Date-Trial	Material	Temperature (°C)	Relative Humidity (%)	Atmospheric Pressure (Millibar)	Dome Pressure (in of H ₂ O)
03/16/93-1	M9	16 - 28	39	26.19	1.19
03/16/93-1	M3	12 - 25	37 - 42	26.12	1.17
03/17/93-2	M3	30 - 42	35	26.06	1.09
03/17/93-3	M3	16 - 22	32 - 40	25.96	1.19
03/18/93-4	M3	11 - 19	67 - 70	26.01	1.14
03/18/93-5	M3	16 - 18	47 - 58	26.16	1.22

Table 4.3 Emission Factors for Volatile Organic Compounds Found During Open burning of M3 Propellant.

OGI ^a Canister No.	DU-77&78	DU-81&82	DU-85&86	DU-89&90	DU-93&94	Average (wt/wt)	Standard Deviation (wt/wt)
Analyte	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)
Carbon tetrachloride	BD ^b	BD	5.66E-07	BD	BD	NA ^c	NA
Methane	7.20E-05	7.77E-06	2.21E-05	2.40E-05	3.38E-05	3.19E-05	2.43E-05
Benzene	2.52E-05	6.65E-06	1.04E-05	1.14E-05	1.35E-05	1.34E-05	7.04E-06
Toluene	BD	2.19E-06	1.96E-06	1.44E-06	8.65E-07	1.61E-06	5.87E-07
n-Propylbenzene	1.69E-07	BD	BD	BD	BD	NA	NA
Ethylbenzene	BD	1.82E-07	BD	3.16E-07	1.37E-07	2.12E-07	9.32E-08
o-Xylene	BD	1.82E-07	4.55E-08	2.26E-07	4.55E-08	1.25E-07	9.31E-08
m-&p-Xylene	BD	6.83E-07	1.05E-06	9.48E-07	2.73E-07	7.38E-07	3.46E-07
Alkanes (Paraffins) ^d	2.70E-05	9.29E-06	2.11E-05	4.60E-05	7.20E-06	2.21E-05	1.57E-05
Alkenes (Olefins)	5.73E-05	1.88E-05	2.81E-05	2.68E-05	2.47E-05	3.11E-05	1.50E-05
Aromatics	2.12E-05	8.93E-06	1.09E-05	1.56E-05	1.79E-05	1.49E-05	5.01E-06
TNMHC	1.40E-04	6.03E-05	9.43E-05	1.10E-04	5.15E-05	9.11E-05	3.61E-05
TO-12 (NMOC)	2.48E-04	1.45E-04	1.73E-04	1.88E-04	1.49E-04	1.81E-04	4.17E-05

^aOregon Graduate Institute of Science and Technology.

^bBelow detection.

^cNot applicable.

^dSee table 3.5 for list of alkanes, alkenes, and aromatics.

4.3.2. Semivolatile Organic Compounds

The SVOCs were assayed from two collection media; (1) the hivol samplers using 20.3 x 25.4-cm quartz fiber filters and the PS-1 samplers using 100mm diameter quartz fiber filters followed by a 60-mm i.d. x 125-mm borosilicate glass cylinder containing XAD-2® resin. Extraction of the hivol media were done by AWL using the method described in Appendix C, Page C-6. Analyses of hivol media extract were done by EPA Method 8270 using GC/MS and by SFC/MS using the methods described in Appendix C, Page C-20 and C-11. Extraction of the PS-1 media were done by Radian Corporation with assay of the extract by EPA Method 8270 using GC/MS, Appendix C, Page C-65.

4.3.2.1. Emission Factors from Hivol Samplers Using the SFC/MS and SFC/TEA Methods

Tables 4.4 through 4.12 show the EF for the semivolatiles found from the SFC/MS and SFC/TEA analyses. The effort of the study was confined to the 18 target analytes on the list (Table 3.6). These methods bring together the attractive characteristics of the three instruments. By monitoring three or more ions that are relatively abundant and characteristic of a particular compound, the MS can function as a very sensitive, selective detector in the CI/SIM mode. However, the selectivity of the detector is dependent upon how specific the ion is to the analyte. Similar compounds tend to have many of the same characteristic ions; hence, the desirability of a chromatographic technique to separate the analytes of a complex mixture prior to introduction into the mass spectrometer. The SFC is an ideal instrument for this purpose. It is capable of separating analytes in complex mixtures at temperatures low enough to protect the integrities of thermally labile compounds such as RDX, HMX, and N-nitrosodiphenylamine. This permits analysis of RDX, HMX and the differentiation of N-nitrosodiphenylamine from diphenylamine, three of the many analytes that cannot be analysed by conventional GC/MS. The TEA is a chemiluminescence detector that is sensitive and selective for nitro- and nitroso-compounds, nitramines, and nitrate esters and is therefore, a very useful tool to analyse such detonation products at very low levels and in complex mixtures. The phenols and naphthalenes may have been lost during the extraction of the media. Target analytes are included if at least one of the samples from the 5 trials indicated the presence of the analyte.

4.3.2.1.1. N-Nitrosodiphenylamine

Table 4.4 shows the EF from the five M3 propellant burn trials. An analysis of variance indicates no significant difference in the trial means. The overall mean EF for N-Nitrosodiphenylamine is 2.68E-08 with a standard deviation of 1.92E-08.

4.3.2.1.2. 2,4-Dinitrotoluene

Table 4.4 Emission Factors for N-Nitrosodiphenylamine With Means and Standard Deviations from the Open Burning of M3 Propellant, as Sampled by Hivol^a and Assayed Using SFC/MS^b.

Date - Trial No.	HiVol-1 EF ^c (wt/wt)	HiVol-2 EF (wt/wt)	HiVol-3 EF (wt/wt)	Average EF (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	BD ^d	BD	6.50E-08	NA ^e	NA
3/17/93 - 2	5.43E-08	8.00E-09	2.00E-08	2.75E-08	2.40E-08
3/17/93 - 3	3.25E-08	2.78E-08	1.89E-08	2.64E-08	6.92E-09
3/18/93 - 4	9.85E-09	5.26E-08	2.53E-08	2.93E-08	2.16E-08
3/18/93 - 5	1.45E-08	1.26E-08	6.65E-09	1.12E-08	4.08E-09

^aHigh-volume sampler.

^bSupercritical fluid chromatography/mass spectrometry.

^cEmission factor.

^dBelow detection.

^eNot applicable.

Table 4.5 shows the EF for 2,4-dinitrotoluene from the five M3 propellant burn trials. An analysis of variance indicates a significant difference in the trial means. A Duncan multiple range test indicates the Trial 2 EF mean to be different from the EF means of Trial 3 and Trial 4 and the Trial 1 EF mean to be different from the EF mean of Trial 4. The overall mean EF for 2,4-Dinitrotoluene is 3.58E-07 with a standard deviation of 1.79E-07.

Table 4.5 Emission Factors for 2,4-Dinitrotoluene With Means and Standard Deviations from the Open Burning of M3 Propellant, as Sampled by Hivol^a and Assayed Using SFC/MS^b.

Date - Trial No.	HiVol-1 EF ^c (wt/wt)	HiVol-2 EF (wt/wt)	HiVol-3 EF (wt/wt)	Average EF (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	3.01E-07	2.61E-07	2.81E-07	2.81E-07	2.04E-08
3/17/93 - 2	1.38E-07	2.07E-07	1.45E-07	1.63E-07	3.76E-08
3/17/93 - 3	4.20E-07	5.65E-07	2.62E-07	4.16E-07	1.52E-07
3/18/93 - 4	7.34E-07	3.19E-07	6.80E-07	5.78E-07	2.26E-07
3/18/93 - 5	2.78E-07	4.20E-07	3.54E-07	3.51E-07	7.07E-08

^aHigh-volume sampler.

^bSupercritical fluid chromatography/mass spectrometry.

^cEmission factor.

4.3.2.1.3. 2,4,6-Trinitrotoluene

Table 4.6 shows the EF from the five M3 propellant burn trials. An analysis of variance indicates a significant difference in the trial means. A Duncan multiple range test indicates the Trial 1 EF mean to be different from the EF means of the other 4 trials and Trial 5 EF mean to be different from the EF mean

of Trial 4. The overall mean EF for 2,4,6-Triinitrotoluene is 1.22E-08 with a standard deviation of 7.05E-09.

Table 4.6 Emission Factors for 2,4,6-Trinitrotoluene With Means and Standard Deviations from the Open Burning of M3 Propellant, as Sampled by Hivol^a and Assayed Using SFC/MS^b.

Date - Trial No.	HiVol-1 EF ^c (wt/wt)	Hivol-2 EF (wt/wt)	Hivol-3 EF (wt/wt)	Average EF (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	1.33E-09	8.96E-10	5.15E-09	2.46E-09	2.34E-09
3/17/93 - 2	1.05E-08	1.52E-08	1.23E-08	1.27E-08	2.39E-09
3/17/93 - 3	1.12E-08	1.84E-08	1.21E-08	1.39E-08	3.91E-09
3/18/93 - 4	1.61E-08	1.50E-08	3.01E-08	2.04E-08	8.45E-09
3/18/93 - 5	1.04E-08	1.26E-08	1.18E-08	1.16E-08	1.10E-09

^aHigh-volume sampler.

^bSupercritical fluid chromatography/mass spectrometry.

^cEmission factor.

4.3.2.1.4. 2-Nitrodiphenylamine

Only one sample on Trial 4 gave any indication of the presence of 2-nitrodiphenylamine from the M-3 propellant burns. The EF from this sample was 3.22E-09. This one positive sample out of 15 samples assayed is strong indication that 2-nitrodiphenylamine is present in non-detectable quantities or is an artifact.

4.3.2.1.5. Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)

Table 4.7 shows the EF from the five M3 propellant burn trials. An analysis of variance indicates a significant difference in the trial means. A Duncan multiple range test indicates Trial 2 EF mean to be different from the EF means of all the other trials. The overall mean EF for RDX is 1.25E-08 with a standard deviation of 9.74E-09.

4.3.2.1.6. 2-Nitropyrene

Table 4.8 shows the EF of the five trials. An analysis of variance indicates no significant difference in the trial means. The overall mean EF for 2-Nitropyrene is 6.99E-10 with a standard deviation of 7.34E-10.

4.3.2.1.7. Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)

Table 4.7 Emission Factors for RDX With Means and Standard Deviations from the Open Burning of M3 Propellant, as Sampled by HiVol^a and Assayed Using SFC/MS^b.

Date - Trial No.	HiVol-1 EF ^c (wt/wt)	HiVol-2 EF (wt/wt)	HiVol-3 EF (wt/wt)	Average EF (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	8.96E-09	8.88E-09	1.30E-08	1.03E-08	2.36E-09
3/17/93 - 2	2.30E-08	3.76E-08	2.71E-08	2.92E-08	7.55E-09
3/17/93 - 3	1.10E-08	1.25E-08	7.39E-09	1.03E-08	2.64E-09
3/18/93 - 4	2.31E-09	1.64E-09	6.45E-09	3.47E-09	2.61E-09
3/18/93 - 5	4.74E-09	1.16E-08	1.20E-08	9.44E-09	4.07E-09

^aHigh-volume sampler.

^bSupercritical fluid chromatography/mass spectrometry.

^cEmission factor.

Table 4.8 Emission Factors for 2-Nitropyrene With Means and Standard Deviations from the Open Burning of M3 Propellant, as Sampled by HiVol^a and Assayed Using SFC/MS^b.

Date - Trial No.	HiVol-1 EF ^c (wt/wt)	HiVol-2 EF (wt/wt)	HiVol-3 EF (wt/wt)	Average EF (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	6.77E-10	3.28E-10	BD ^d	5.02E-10	2.47E-10
3/17/93 - 2	BD	8.23E-10	4.06E-10	6.15E-10	2.95E-10
3/17/93 - 3	1.73E-10	1.62E-10	4.59E-10	2.65E-10	1.68E-10
3/18/93 - 4	1.89E-10	BD	5.07E-10	3.48E-10	2.25E-10
3/18/93 - 5	2.59E-10	2.02E-09	2.38E-09	1.55E-09	1.14E-09

^aHigh-volume sampler.

^bSupercritical fluid chromatography/mass spectrometry.

^cEmission factor.

^dBelow detection.

HMX was found on 3 samples out of a total of 15 samples. These all occurred on the first 2 trials resulting in EF of 7.48E-10, 9.83E-11, and 1.88E-10. HMX is usually present in low quantities whenever RDX is present.

4.3.2.1.8. Dibenzofuran

Dibenzofuran was found on Trials 1, 3, and 5, Table 4.9. The overall mean EF for Dibenzofuran is 4.46E-08 with a standard deviation of 1.68E-08.

4.3.2.1.9. Diphenylamine

Table 4.9 Emission Factors for Dibenzofuran With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by HiVol^a and Assayed Using SFC/MS^b.

Date - Trial No.	HiVol-1 EF ^c (wt/wt)	HiVol-2 EF (wt/wt)	HiVol-3 EF (wt/wt)	Average EF (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	4.99E-08	9.50E-09	BD ^d	2.97E-08	2.85E-08
3/17/93 - 2	BD	BD	BD	NA ^e	NA
3/17/93 - 3	BD	BD	BD	NA	NA
3/18/93 - 4	4.19E-08	4.42E-08	5.53E-08	4.71E-08	7.15E-09
3/18/93 - 5	6.90E-08	4.36E-08	4.35E-08	5.21E-08	1.47E-08

^aHigh-volume sampler.

^bSupercritical fluid chromatography/mass spectrometry.

^cEmission factor.

^dBelow detection.

^eNot applicable.

Diphenylamine was found only on Trials 4 and 5. The EF for the quantities found were 1.24E-08 on trial 4 and 4.35E-09, 4.13E-09, and 1.74E-09 on Trial 5. The overall mean EF for Diphenylamine is 5.70E-09 with a standard deviation of 4.64E-09.

4.3.2.1.10. Pyrene

Table 4.10 shows the EF of the five trials. An analysis of variance indicates a significant difference in the trial means. A Duncan multiple range test indicates Trial 3 EF mean to be different from the EF means of all the other trials. The overall mean EF for Pyrene is 4.31E-08 with a standard deviation of 3.98E-08.

Table 4.10 Emission Factors for Pyrene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by HiVol^a and Assayed Using SFC/MS^b.

Date - Trial No.	HiVol-1 EF ^c (wt/wt)	HiVol-2 EF (wt/wt)	HiVol-3 EF (wt/wt)	Average EF (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	4.04E-08	3.54E-08	2.09E-08	3.22E-08	1.01E-08
3/17/93 - 2	1.47E-08	2.54E-08	3.16E-08	2.39E-08	8.57E-09
3/17/93 - 3	9.06E-08	1.11E-07	1.46E-07	1.16E-07	2.82E-08
3/18/93 - 4	2.51E-08	1.37E-08	2.58E-08	2.15E-08	6.78E-09
3/18/93 - 5	1.70E-08	1.74E-08	3.16E-08	2.20E-08	8.30E-09

^aHigh-volume sampler.

^bSupercritical fluid chromatography/mass spectrometry.

^cEmission factor.

4.3.2.1.11. Benz(a)anthracene

Table 4.11 shows the EF of the five trials. An analysis of variance indicates no significant difference in the trial means. The overall mean EF for benz(a)anthracene is 8.79E-09 with a standard deviation of 6.81E-09.

Table 4.11 Emission Factors for Benz(a)anthracene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by HiVol^a and Assayed Using SFC/MS^b.

Date - Trial No.	HiVol-1 EF ^c (wt/wt)	HiVol-2 EF (wt/wt)	HiVol-3 EF (wt/wt)	Average EF (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	BD ^d	7.21E-09	5.00E-09	6.10E-09	1.56E-09
3/17/93 - 2	5.64E-09	5.64E-09	6.50E-09	5.93E-09	4.94E-10
3/17/93 - 3	7.79E-09	9.98E-09	1.30E-08	1.03E-08	2.61E-09
3/18/93 - 4	4.61E-09	3.16E-09	5.53E-09	4.43E-09	1.20E-09
3/18/93 - 5	8.63E-09	9.65E-09	3.07E-08	1.63E-08	1.25E-08

^aHigh-volume sampler.

^bSupercritical fluid chromatography/mass spectrometry.

^cEmission factor.

^dBelow detection.

4.3.2.1.12. Benz(a)pyrene

Table 4.11 shows the EF of the five trials. An analysis of variance indicates no significant difference in the trial means. The overall mean EF for benz(a)pyrene is 7.71E-09 with a standard deviation of 3.43E-09.

Table 4.12 Emission Factors for Benz(a)pyrene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by HiVol^a and Assayed Using SFC/MS^b.

Date - Trial No.	HiVol-1 EF ^c (wt/wt)	HiVol-2 EF (wt/wt)	HiVol-3 EF (wt/wt)	Average EF (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	1.16E-08	1.29E-08	4.67E-09	9.73E-09	4.44E-09
3/17/93 - 2	8.15E-09	4.94E-09	5.69E-09	6.26E-09	1.68E-09
3/17/93 - 3	6.71E-09	7.89E-09	9.68E-09	8.09E-09	1.50E-09
3/18/93 - 4	4.19E-09	4.63E-09	6.22E-09	5.01E-09	1.07E-09
3/18/93 - 5	5.39E-09	7.12E-09	1.59E-08	9.46E-09	5.62E-09

^aHigh-volume sampler.

^bSupercritical fluid chromatography/mass spectrometry.

^cEmission factor.

4.3.2.2. Emission Factors from Hivol Samplers Using the EPA Method 8270

Tables 4.13 through 4.21 shows the EF for the semivolatiles found when using EPA Method 8270.

4.3.2.2.1. Acetophenone

Acetophenone was found on one sample on Trial 1, Trial 2, and Trial 3. The EF for the quantities found were 9.87E-09 on Trial 1, 2.86E-08 on Trial 2, and 1.38E-08 on Trial 3. The overall mean EF for acetophenone is 1.74E-08 with a standard deviation of 9.88E-09.

4.3.2.2.2. Benzo(b)fluoranthene

Benzo(b)fluoranthene was found on one of 15 samples with an EF of 1.97E-08.

4.3.2.2.3. Benzo(ghi)perylene

Benzo(ghi)perylene was found on one of 15 samples with an EF of 9.87E-09.

4.3.2.2.4. Bis(2-Ethylhexyl) Phthalate

Table 4.13 shows the EF for the five trials. An analysis of variance indicates no significant difference in the bis(2-ethylhexyl) phthalate EF means over the 5 trials. The overall mean EF for bis(2-ethylhexyl) phthalate was 1.72E-07 with a standard deviation of 1.58E-07.

4.3.2.2.5. Butylbenzyl Phthalate

Table 4.13 Emission Factors for Bis(2-Ethylhexyl) Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by Hivol^a and Assayed Using USEPA Method 8270.

Date - Trial No.	HiVol-1 (wt/wt)	HiVol-2 (wt/wt)	HiVol-3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	7.62E-08	1.11E-07	1.16E-07	1.01E-07	2.15E-08
3/17/93 - 2	1.99E-07	2.51E-07	6.51E-07	3.67E-07	2.47E-07
3/17/93 - 3	1.41E-07	1.13E-07	2.38E-07	1.64E-07	6.53E-08
3/18/93 - 4	BD ^b	BD	1.50E-08	NA ^c	NA
3/18/93 - 5	9.77E-08	7.99E-08	1.42E-07	1.07E-07	3.21E-08

^aHigh-volume sampler.

^bBelow detection.

^cNot applicable.

Table 4.14 shows the EF for the five trials. An analysis of variance indicates no significant difference in the butylbenzyl phthalate EF means. The overall mean EF for butylbenzyl phthalate was 3.81E-08 with a standard deviation of 4.63E-08.

Table 4.14 Emission Factors for Butylbenzyl Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by Hivol^a and Assayed Using USEPA Method 8270.

Date - Trial No.	HiVol-1 (wt/wt)	HiVol-2 (wt/wt)	HiVol-3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	BD ^b	BD	8.29E-09	NA ^c	NA
3/17/93 - 2	1.79E-08	1.95E-08	1.28E-07	5.52E-08	6.32E-08
3/17/93 - 3	4.65E-08	8.38E-09	BD	2.74E-08	2.70E-08
3/18/93 - 4	BD	BD	BD	NA	NA
3/18/93 - 5	BD	BD	BD	NA	NA

^aHigh-volume sampler.

^bBelow detection.

^cNot applicable.

4.3.2.2.6. Di-n-Butyl Phthalate

Table 4.15 shows the EF for the five trials. An analysis of variance indicates no significant difference in the di-n-butyl phthalate EF means. The overall mean EF for di-n-butyl phthalate was 1.62E-06 with a standard deviation of 1.09E-06.

4.3.2.2.7. Diethyl Phthalate

Table 4.15 Emission Factors for Di-n-Butyl Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by Hivol^a and Assayed Using USEPA Method 8270.

Date - Trial No.	HiVol-1	HiVol-2	HiVol-3	Average	Standard Deviation
	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)
3/16/93 - 1	9.93E-07	9.11E-07	5.76E-07	8.27E-07	2.21E-07
3/17/93 - 2	9.53E-07	1.21E-06	1.44E-06	1.20E-06	2.42E-07
3/17/93 - 3	BD ^b	1.45E-06	3.92E-08	7.46E-07	1.00E-06
3/18/93 - 4	3.13E-06	4.82E-07	3.07E-06	2.23E-06	1.51E-06
3/18/93 - 5	2.51E-06	2.69E-06	3.24E-06	2.81E-06	3.80E-07

^aHigh-volume sampler.

^bBelow detection.

Diethyl phthalate was found on 4 of 15 samples. The EF for the quantities found were 8.67E-09 on Trial 1, 3.11E-07 on Trial 2, 4.63E-08 on Trial 3, and 1.26E-08 on Trial 5. The overall mean EF for diethyl phthalate was 9.46E-08 with a standard deviation of 1.45E-07.

4.3.2.2.8. Dimethyl Phthalate

Dimethyl phthalate was found on 5 of 15 samples, Table 4.16. The overall mean was 4.13E-08 with a standard deviation of 3.02E-08.

Table 4.16 Emission Factors for Dimethyl Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by Hivol^a and Assayed Using USEPA Method 8270.

Date - Trial No.	HiVol-1	HiVol-2	HiVol-3	Average	Standard Deviation
	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)
3/16/93 - 1	BD ^b	2.00E-08	3.63E-08	2.82E-08	1.15E-08
3/17/93 - 2	BD	BD	7.89E-08	NA	NA
3/17/93 - 3	6.46E-08	6.62E-09	BD	3.56E-08	4.10E-08
3/18/93 - 4	BD	BD	BD	NA ^c	NA
3/18/93 - 5	BD	BD	BD	NA	NA

^aHigh-volume sampler.

^bBelow detection.

^cNot applicable.

4.3.2.2.9. 2,4-Dinitrotoluene

Table 4.17 shows the 2,4-dinitrotoluene EF for the five trials. An analysis of variance indicates the EF

mean for Trial 3 to be significantly different from the EF factor means of Trial 2, Trial 4, and Trial 5. The overall mean EF for 2,4-dinitrotoluene was 1.55E-07 with a standard deviation of 1.32E-07.

Table 4.17 Emission Factors for 2,4-Dinitrotoluene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by Hivol^a and Assayed Using USEPA Method 8270.

Date - Trial No.	HiVol-1 (wt/wt)	HiVol-2 (wt/wt)	HiVol-3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	1.59E-07	2.23E-07	2.17E-07	2.00E-07	3.52E-08
3/17/93 - 2	3.18E-08	3.55E-08	BD ^b	3.36E-08	2.60E-09
3/17/93 - 3	5.24E-07	1.87E-07	BD	3.55E-07	2.39E-07
3/18/93 - 4	1.69E-07	9.64E-08	1.88E-07	1.51E-07	4.83E-08
3/18/93 - 5	1.07E-07	3.62E-08	4.59E-08	6.30E-08	3.82E-08

^aHigh-volume sampler.

^bBelow detection.

4.3.2.2.10. Di-n-Octyl Phthalate

Table 4.18 shows the di-n-octyl phthalate EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall mean EF for di-n-octyl phthalate was 4.19E-08 with a standard deviation of 4.24E-08.

Table 4.18 Emission Factors for Di-n-Octyl Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by Hivol^a and Assayed Using USEPA Method 8270.

Date - Trial No.	HiVol-1 (wt/wt)	HiVol-2 (wt/wt)	HiVol-3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	BD ^b	BD	BD	NA ^c	NA
3/17/93 - 2	1.79E-08	1.95E-08	1.16E-07	5.13E-08	5.64E-08
3/17/93 - 3	3.70E-08	1.85E-08	BD	2.78E-08	1.31E-08
3/18/93 - 4	BD	BD	BD	NA	NA
3/18/93 - 5	BD	BD	BD	NA	NA

^aHigh-volume sampler.

^bBelow detection.

^cNot applicable.

4.3.2.2.11. Fluoranthene

Table 4.19 shows the fluoranthene EF for the five trials. An analysis of variance indicates no significant

difference in the EF means. The overall mean EF for fluoranthene was 4.62E-08 with a standard deviation of 2.89E-08.

Table 4.19 Emission Factors for Fluoranthene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by Hivol^a and Assayed Using USEPA Method 8270.

Date - Trial No.	HiVol-1 (wt/wt)	HiVol-2 (wt/wt)	HiVol-3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	3.19E-08	4.05E-08	3.95E-08	3.73E-08	4.74E-09
3/17/93 - 2	BD ^b	BD	4.73E-08	NA ^c	NA
3/17/93 - 3	1.04E-07	5.07E-08	BD	7.73E-08	3.77E-08
3/18/93 - 4	BD	9.20E-09	BD	NA	NA
3/18/93 - 5	BD	BD	BD	NA	NA

^aHigh-volume sampler.

^bBelow detection.

^cNot applicable.

4.3.2.2.12. 2-Nitrophenol

2-Nitrophenol was found on one of 15 samples with an EF of 2.23E-08.

4.3.2.2.13. 4-Nitrophenol

Table 4.20 shows the 4-nitrophenol EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall mean EF for 4-nitrophenol was 2.58E-07 with a standard deviation of 5.63E-07.

4.3.2.2.14. Phenanthrene

Phenanthrene was found on 3 of 15 samples. The EF for the quantities found were 1.97E-09 on Trial 1, 2.37E-08 on Trial 2, and 3.78E-08 on Trial 3. The overall mean EF for phenanthrene was 2.71E-08 with a standard deviation of 9.50E-09.

4.3.2.2.15. Pyrene

Table 4.21 shows the pyrene EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall mean EF for pyrene was 5.96E-08 with a standard deviation of 2.84E-08.

Table 4.20 Emission Factors for 4-Nitrophenol With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by Hivol^a and Assayed Using USEPA Method 8270.

Date - Trial No.	HiVol-1 (wt/wt)	HiVol-2 (wt/wt)	HiVol-3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	6.37E-08	6.08E-08	9.87E-08	7.44E-08	2.11E-08
3/17/93 - 2	BD	3.09E-08	BD	NA ^c	NA
3/17/93 - 3	6.62E-08	BD	1.65E-06	8.58E-07	1.12E-06
3/18/93 - 4	BD	3.68E-08	6.01E-08	4.85E-08	1.65E-08
3/18/93 - 5	BD	BD	BD	NA	NA

^aHigh-volume sampler.

^bBelow detection.

^cNot applicable.

Table 4.21 Emission Factors for Pyrene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by Hivol^a and Assayed Using USEPA Method 8270.

Date - Trial No.	HiVol-1 (wt/wt)	HiVol-2 (wt/wt)	HiVol-3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	9.70E-08	4.05E-08	3.95E-08	5.90E-08	3.29E-08
3/17/93 - 2	BD ^b	BD	3.55E-08	NA ^c	NA
3/17/93 - 3	9.45E-08	5.07E-08	BD	7.26E-08	3.10E-08
3/18/93 - 4	BD	BD	BD	NA	NA
3/18/93 - 5	BD	BD	BD	NA	NA

^aHigh-volume sampler.

^bBelow detection.

^cNot applicable.

4.3.2.2.16. Benzoic Acid

Benzoic acid was found on 2 of 15 samples. The EF are 9.20E-09 and 6.01E-07 with a mean of 3.05E-07 and a standard deviation of 4.19E-07.

4.3.2.3. Emission Factors from PS-1 Samplers Using the EPA Method 8270

Tables 4.22 through 4.24 shows the EF for the semivolatiles found when using the EPA Method 8270. Analytes reported at measurable levels (near or above the Practical Quantitation Limit (PQL)) include phenol, acetophenone, 2,4-dinitrotoluene, di-n-butyl phthalate, and bis(2-ethylhexyl) phthalate. Other compounds are reported at a level well below the PQL. Compounds at levels below the PQL are observed and can be identified reliably, but the confidence level for the quantitative values is far lower.

4.3.2.3.1. Phenol

Table 4.22 shows the phenol EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for phenol was 2.01E-06 with a standard deviation of 1.59E-06.

Table 4.22 Emission Factors for Phenol With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	2.36E-06	4.50E-07	1.41E-06	1.35E-06
3/17/93 - 2	2.93E-06	5.61E-06	2.94E-06	3.83E-06	1.54E-06
3/17/93 - 3	BD	4.77E-07	BD	NA ^b	NA
3/18/93 - 4	BD	9.00E-07	BD	NA	NA
3/18/93 - 5	2.09E-06	1.63E-06	6.92E-07	1.47E-06	7.11E-07

^aBelow detection.

^bNot applicable.

4.3.2.3.2. Acetophenone

Table 4.23 shows the acetophenone EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for acetophenone was 2.09E-06 with a standard deviation of 1.89E-06.

Table 4.23 Emission Factors for Acetophenone With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	5.33E-07	3.89E-06	2.48E-06	2.30E-06	1.69E-06
3/17/93 - 2	2.50E-06	7.23E-06	3.51E-06	4.42E-06	2.49E-06
3/17/93 - 3	1.96E-07	1.60E-06	BD ^a	8.98E-07	9.93E-07
3/18/93 - 4	3.14E-07	1.12E-06	3.39E-07	5.89E-07	4.56E-07
3/18/93 - 5	1.25E-06	2.63E-06	1.72E-06	1.87E-06	7.03E-07

^aBelow detection.

4.3.2.3.3. 2-Nitrophenol

2-Nitrophenol was found in the 3 samples from Trial 1. The EF were 4.32E-07, 3.31E-07, and 3.82E-07

with a mean of 3.82E-07 and a standard deviation of 7.19E-08.

4.3.2.3.4. 2,4-Dimethylphenol

Table 4.24 shows the 2,4-dimethylphenol EF for the five trials. An analysis of variance indicates no significant difference in the EF means of the two trials where 2,4-dimethylphenol was found. The overall EF mean for 2,4-dimethylphenol was 6.06E-07 with a standard deviation of 1.70E-07.

Table 4.24 Emission Factors for 2,4-Dimethylphenol With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	BD	BD	NA ^b	NA
3/17/93 - 2	BD	BD	BD	NA	NA
3/17/93 - 3	BD	BD	BD	NA	NA
3/18/93 - 4	5.45E-07	7.03E-07	3.22E-07	5.23E-07	1.91E-07
3/18/93 - 5	5.67E-07	8.17E-07	6.80E-07	6.88E-07	1.25E-07

^aBelow detection.

^bNot applicable.

4.3.2.3.5. a,a-Dimethylphenethylamine

Table 4.25 shows the a,a-dimethylphenethylamine EF for the five trials. An analysis of variance indicates a significant difference in the EF means of a,a-dimethylphenethylamine. Trial 2 EF mean was significantly different from all the other trial EF. The overall EF mean for a,a-dimethylphenethylamine was 2.02E-07 with a standard deviation of 1.71E-07.

4.3.2.3.6. Naphthalene

Table 4.26 shows the naphthalene EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for naphthalene was 9.97E-07 with a standard deviation of 4.77E-07.

4.3.2.3.7. 2-Methylnaphthalene

Table 4.27 shows the 2-methylnaphthalene EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for 2-methylnaphthalene was 2.39E-07 with a standard deviation of 2.26E-07.

Table 4.25 Emission Factors for *a,a*-Dimethylphenethylamine With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	1.36E-07	BD	NA	NA
3/17/93 - 2	4.31E-07	5.43E-07	4.00E-07	4.58E-07	7.50E-08
3/17/93 - 3	8.33E-08	7.31E-08	BD	7.82E-08	7.20E-09
3/18/93 - 4	4.49E-08	2.10E-07	2.54E-08	9.33E-08	1.01E-07
3/18/93 - 5	1.38E-07	2.59E-07	8.35E-08	1.60E-07	9.00E-08

^aBelow detection.

^bNot applicable.

Table 4.26 Emission Factors for Naphthalene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	1.84E-06	7.80E-07	1.31E-06	7.51E-07
3/17/93 - 2	3.46E-07	1.09E-06	5.54E-07	6.62E-07	3.82E-07
3/17/93 - 3	5.91E-07	1.02E-06	BD	8.03E-07	3.00E-07
3/18/93 - 4	6.35E-07	1.12E-06	5.34E-07	7.64E-07	3.14E-07
3/18/93 - 5	1.41E-06	1.74E-06	1.30E-06	1.48E-06	2.31E-07

^aBelow detection.

Table 4.27 Emission Factors for 2-Methylnaphthalene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	BD	BD	NA ^b	NA
3/17/93 - 2	2.59E-07	8.14E-07	2.31E-07	4.35E-07	3.29E-07
3/17/93 - 3	BD	3.27E-07	BD	NA	NA
3/18/93 - 4	4.49E-08	2.10E-07	2.54E-08	9.33E-08	1.01E-07
3/18/93 - 5	1.38E-07	2.59E-07	8.35E-08	1.60E-07	9.00E-08

^aBelow detection.

^bNot applicable.

4.3.2.3.8. Dimethyl Phthalate

Table 4.28 shows the dimethyl phthalate EF for the five trials. An analysis of variance indicates a

significant difference in the EF means. A Duncan multiple range test indicates the EF mean from Trial 3 to be significantly larger than the mean EF from the other trials. The overall EF mean for dimethyl phthalate was 3.44E-07 with a standard deviation of 4.64E-07.

Table 4.28 Emission Factors for Dimethyl Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	2.57E-07	1.36E-07	BD ^a	1.97E-07	8.55E-08
3/17/93 - 2	8.65E-08	2.71E-07	7.69E-08	1.45E-07	1.10E-07
3/17/93 - 3	BD	1.56E-06	BD	NA ^b	NA
3/18/93 - 4	BD	BD	BD	NA	NA
3/18/93 - 5	1.38E-07	2.59E-07	3.10E-07	2.36E-07	8.83E-08

^aBelow detection.

^bNot applicable.

4.3.2.3.9. Acenaphthylene

Table 4.29 shows the acenaphthylene EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for acenaphthylene was 4.81E-07 with a standard deviation of 5.70E-07.

Table 4.29 Emission Factors for Acenaphthylene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	2.67E-07	2.16E-06	1.32E-06	1.25E-06	9.50E-07
3/17/93 - 2	2.06E-07	1.27E-07	7.24E-08	1.35E-07	6.75E-08
3/17/93 - 3	1.61E-07	3.81E-07	BD ^a	2.71E-07	1.55E-07
3/18/93 - 4	2.95E-07	2.80E-07	2.54E-07	2.77E-07	2.05E-08
3/18/93 - 5	4.94E-07	3.34E-07	3.82E-07	4.03E-07	8.23E-08

^aBelow detection.

4.3.2.3.10. 2,4-Dinitrotoluene

Table 4.30 shows the 2,4-dinitrotoluene EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for 2,4-dinitrotoluene was 6.21E-06 with a standard deviation of 3.69E-06.

Table 4.30 Emission Factors for 2,4-Dinitrotoluene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	5.06E-06	1.04E-05	4.96E-06	6.80E-06	3.10E-06
3/17/93 - 2	BD ^a	1.31E-05	7.40E-06	1.02E-05	4.01E-06
3/17/93 - 3	6.16E-06	1.13E-05	3.94E-06	7.13E-06	3.78E-06
3/18/93 - 4	3.53E-06	7.07E-06	2.33E-06	4.31E-06	2.46E-06
3/18/93 - 5	1.62E-06	8.97E-06	1.16E-06	3.92E-06	4.38E-06

^aBelow detection.

4.3.2.3.11. Dibenzofuran

Table 4.31 shows the dibenzofuran EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for dibenzofuran was 7.73E-08 with a standard deviation of 3.17E-08.

Table 4.31 Emission Factors for Dibenzofuran With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	8.65E-08	6.61E-08	7.63E-08	1.44E-08
3/17/93 - 2	BD	1.35E-07	7.40E-08	1.05E-07	4.33E-08
3/17/93 - 3	BD	BD	BD	NA ^b	NA
3/18/93 - 4	BD	BD	BD	NA	NA
3/18/93 - 5	5.67E-08	BD	4.53E-08	5.10E-08	8.03E-09

^aBelow detection.

^bNot applicable.

4.3.2.3.12. Diethyl Phthalate

Table 4.32 shows the diethyl phthalate EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for diethyl phthalate was 1.83E-06 with a standard deviation of 3.61E-06.

4.3.2.3.13. 4-Aminobiphenyl

4-Aminobiphenyl was found in one sample out of 15 samples collected in the 5 M-3 trials. The EF for 4-aminobiphenyl was 3.51E-07.

Table 4.32 Emission Factors for Diethyl Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	1.14E-06	8.03E-07	9.70E-07	2.36E-07
3/17/93 - 2	1.74E-07	1.36E-06	3.84E-07	6.39E-07	6.31E-07
3/17/93 - 3	BD	BD	BD	NA ^b	NA
3/18/93 - 4	1.80E-07	1.14E-05	BD	5.78E-06	7.92E-06
3/18/93 - 5	2.69E-07	BD	7.87E-07	5.28E-07	3.66E-07

^aBelow detection.

^bNot applicable.

4.3.2.3.14. Phenanthrene

Table 4.33 shows the phenanthrene EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for phenanthrene was 2.65E-07 with a standard deviation of 2.06E-07.

4.3.2.3.15. Phenacetin

Phenacetin was found on 2 samples on Trial 3. The EF for these samples were 2.12E-07 and 4.35E-07.

4.3.2.3.16. Di-n-Butyl Phthalate

Table 4.34 shows the di-n-butyl phthalate EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for di-n-butyl phthalate was 8.75E-06 with

Table 4.33 Emission Factors for Phenanthrene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	5.05E-08	7.76E-07	4.18E-07	4.15E-07	3.63E-07
3/17/93 - 2	8.65E-08	2.71E-07	7.69E-08	1.45E-07	1.10E-07
3/17/93 - 3	BD ^a	BD	BD	NA ^b	NA
3/18/93 - 4	1.27E-07	2.95E-07	1.07E-07	1.76E-07	1.03E-07
3/18/93 - 5	2.25E-07	3.49E-07	3.96E-07	3.23E-07	8.81E-08

^aBelow detection.

^bNot applicable.

a standard deviation of 5.16E-06.

Table 4.34 Emission Factors for Di-n-Butyl Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	2.65E-06	7.62E-06	5.10E-06	5.12E-06	2.49E-06
3/17/93 - 2	8.17E-06	1.17E-05	8.28E-06	9.39E-06	2.02E-06
3/17/93 - 3	6.15E-06	1.91E-05	2.44E-07	8.50E-06	9.64E-06
3/18/93 - 4	9.76E-06	1.29E-05	8.94E-06	1.05E-05	2.11E-06
3/18/93 - 5	1.43E-05	2.00E-06	1.43E-05	1.02E-05	7.10E-06

4.3.2.3.17. Fluoranthene

Table 4.35 shows the fluoranthene EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for fluoranthene was 2.26E-07 with a standard deviation of 1.41E-07.

Table 4.35 Emission Factors for Fluoranthene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	4.32E-07	1.65E-07	2.99E-07	1.89E-07
3/17/93 - 2	2.06E-07	3.97E-07	7.24E-08	2.25E-07	1.63E-07
3/17/93 - 3	1.61E-07	3.81E-07	BD	2.71E-07	1.55E-07
3/18/93 - 4	5.45E-08	1.05E-07	4.83E-08	6.94E-08	3.13E-08
3/18/93 - 5	2.83E-07	4.08E-07	2.27E-07	3.06E-07	9.30E-08

^aBelow detection.

4.3.2.3.18. Pyrene

Table 4.36 shows the pyrene EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for pyrene was 1.61E-07 with a standard deviation of 9.84E-08.

4.3.2.3.19. Butylbenzyl Phthalate

Table 4.36 Emission Factors for Pyrene With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	BD	1.65E-07	NA ^b	NA
3/17/93 - 2	1.89E-07	1.54E-07	5.54E-08	1.33E-07	6.94E-08
3/17/93 - 3	1.44E-07	3.62E-07	BD	2.53E-07	1.54E-07
3/18/93 - 4	5.45E-08	1.05E-07	4.83E-08	6.94E-08	3.13E-08
3/18/93 - 5	2.83E-07	2.04E-07	BD	2.44E-07	5.60E-08

^aBelow detection.

^bNot applicable.

Table 4.37 shows the butylbenzyl phthalate EF for the five trials. An analysis of variance indicates a significant difference in the EF means. A Duncan multiple range test indicates the EF mean from Trial 2 to be significantly larger than the mean EF from the other trials. The overall EF mean for butylbenzyl phthalate was 1.67E-07 with a standard deviation of 1.56E-07.

Table 4.37 Emission Factors for Butylbenzyl Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	1.36E-07	7.10E-08	1.04E-07	4.61E-08
3/17/93 - 2	3.44E-07	2.71E-07	5.70E-07	3.95E-07	1.56E-07
3/17/93 - 3	4.16E-08	3.66E-08	BD	3.91E-08	3.60E-09
3/18/93 - 4	1.80E-08	1.19E-07	1.07E-07	8.12E-08	5.51E-08
3/18/93 - 5	2.25E-07	6.29E-08	1.69E-07	1.53E-07	8.25E-08

^aBelow detection.

4.3.2.3.20. Bis(2-Ethylhexyl) Phthalate

Table 4.38 shows the bis(2-ethylhexyl) phthalate EF for the five trials. An analysis of variance indicates no significant difference in the EF means. The overall EF mean for bis(2-ethylhexyl) phthalate was 3.80E-06 with a standard deviation of 4.42E-06.

4.3.2.3.21. Di-n-Octyl Phthalate

Table 4.39 shows the di-n-octyl phthalate EF for the five trials. An analysis of variance indicates no

Table 4.38 EF for Bis(2-Ethylhexyl) Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	6.97E-07	BD	NA ^b	NA
3/17/93 - 2	2.94E-06	6.79E-06	1.35E-05	7.75E-06	5.36E-06
3/17/93 - 3	BD	BD	BD	NA	NA
3/18/93 - 4	BD	5.55E-07	1.28E-06	9.17E-07	5.13E-07
3/18/93 - 5	1.40E-06	BD	3.22E-06	2.31E-06	1.29E-06

^aBelow detection.

^bNot applicable.

significant difference in the EF means. The overall EF mean for di-n-octyl phthalate was 8.64E-08 with a standard deviation of 7.82E-08.

Table 4.39 Emission Factors for Di-n-Octyl Phthalate With Means and Standard Deviations from the Open Burning of M-3 Propellant, as Sampled by PS-1 and Assayed Using USEPA Method 8270.

Date - Trial No.	(wt/wt)	(wt/wt)	(wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
3/16/93 - 1	BD ^a	BD	BD	NA ^b	NA
3/17/93 - 2	2.24E-07	1.90E-07	8.94E-08	1.68E-07	6.98E-08
3/17/93 - 3	8.33E-09	5.08E-08	BD	2.96E-08	3.00E-08
3/18/93 - 4	BD	5.61E-08	BD	NA	NA
3/18/93 - 5	4.22E-08	BD	3.10E-08	3.66E-08	7.88E-09

^aBelow detection.

^bNot applicable.

4.3.3. Untargeted GC/MS Analytes of Potential Interest from Hivol Sampler

MSA conducted an extensive mass spectral library search of compounds not identified as Appendix IX Semi-Volatile Compounds. This data is available in event it becomes desirable to interpret it.

4.3.4. SFC/TEA and SFC/MS New Compounds of Potential Interest from Hivol Sampler

Composite filter extracts were analyzed by SFC/TEA. The TEA is a chemiluminescence detector that is sensitive and selective for nitro- and nitroso-containing compounds and nitrate esters. SFC/TEA operating procedures are contained in AWL LOI-8. The TEA is useful for detection of analytes that may be by-products of explosives detonations. From the retention times of standards, peaks in the SFC/TEA chromatograms can be tentatively identified and/or selected for analysis by SFC/CI/SIM/MS. This method is capable of detecting very low levels of target analytes in complex mixtures. It is especially suited to the analysis of these compounds, which will not survive the temperatures necessary for GC/MS analysis.

4.3.5. Tentatively Identified Compounds (TIC) from PS-1 Sampler

TIC are reported for all the PS-1 samples in Appendix G, Tables 23 through 28 .

4.3.6. Metals

The M-3 propellant material contained no metals as constituents of the M-1 propellant. Trace amounts of the metals could be present from manufacturing processes and the ignition material. The EF for the elements found are given in Tables 4.40 through 4.46.

4.3.6.1. Aluminum

Aluminum was found on 4 samples out of a total of 15 samples, Table 4.40. The overall mean was $9.81\text{E-}06$ with a standard deviation of $1.74\text{E-}05$.

4.3.6.2. Cadmium

Cadmium was found in one sample out of a total of 15 collected. The EF for this sample was $1.59\text{E-}07$.

4.3.6.3. Calcium

Calcium was found in all 15 samples in a very uniform amount, Table 4.41. The EF means from the 5 trials were not significantly different. The overall mean was $4.29\text{E-}05$ with a standard deviation of 1.10E-

Table 4.40 Emission Factors for Aluminum with Means and Standard Deviations from the Open Burning of M-3 Propellant as Sampled by Hivol and Assayed by ICP^a Method.

Date - Trial No.	HiVol 1 (wt/wt)	HiVol 2 (wt/wt)	HiVol 3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	BD ^b	BD	2.03E-06	NA ^c	NA
3/17/93 - 2	BD	1.65E-06	1.90E-06	1.77E-06	1.76E-07
3/17/93 - 3	BD	BD	2.55E-06	NA	NA
3/18/93 - 4	BD	BD	BD	NA	NA
3/18/93 - 5	BD	BD	4.09E-05	NA	NA

^aInductively coupled plasma atomic emission spectrometry EPA-SW-846-6010.

^bBelow detection.

^cNot applicable.

05.

Table 4.41 Emission Factors for Calcium with Means and Standard Deviations from the Open Burning of M-3 Propellant as Sampled by Hivol and Assayed by ICP^a Method.

Date - Trial	HiVol 1 (wt/wt)	HiVol 2 (wt/wt)	HiVol 3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	3.16E-05	3.24E-05	3.83E-05	3.41E-05	3.68E-06
3/17/93 - 2	3.97E-05	5.17E-05	6.23E-05	5.12E-05	1.13E-05
3/17/93 - 3	3.68E-05	4.41E-05	6.63E-05	4.91E-05	1.53E-05
3/18/93 - 4	2.93E-05	3.58E-05	4.61E-05	3.71E-05	8.43E-06
3/18/93 - 5	3.45E-05	4.36E-05	5.12E-05	4.31E-05	8.35E-06

^aInductively coupled plasma atomic emission spectrometry EPA-SW-846-6010.

4.3.6.4. Copper

Copper was found on all 15 samples, Table 4.42. The means were significantly different with Trials 2 and 3 means larger than the means of Trials 1, 5, and 4. The overall mean was 4.23E-06 with a standard deviation of 3.04E-06.

4.3.6.5. Lead

Lead was found on all 15 samples in a very uniform amount, Table 4.43. There was no significant difference in the trial means. The overall mean was 4.07E-06 with a standard deviation of 9.01E-07.

Table 4.42 Emission Factors for Copper with Means and Standard Deviations from the Open Burning of M-3 Propellant as Sampled by Hivol and Assayed by ICP^a Method.

Date - Trial	HiVol 1 (wt/wt)	HiVol 2 (wt/wt)	HiVol 3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	1.31E-06	6.22E-07	1.86E-06	1.26E-06	6.18E-07
3/17/93 - 2	4.67E-06	5.50E-06	8.27E-06	6.15E-06	1.89E-06
3/17/93 - 3	6.01E-06	7.28E-06	1.16E-05	8.29E-06	2.92E-06
3/18/93 - 4	2.11E-06	2.62E-06	4.05E-06	2.93E-06	1.00E-06
3/18/93 - 5	1.66E-06	2.25E-06	3.70E-06	2.54E-06	1.05E-06

^aInductively coupled plasma atomic emission spectrometry EPA-SW-846-6010.

Table 4.43 Emission Factors for Lead with Means and Standard Deviations from the Open Burning of M-3 Propellant as Sampled by Hivol and Assayed by ICP^a Method.

Date - Trial	HiVol 1 (wt/wt)	HiVol 2 (wt/wt)	HiVol 3 (wt/wt)	Average (wt/wt)	Standard Deviation (wt/wt)
3/16/93 - 1	3.40E-06	3.24E-06	3.83E-06	3.49E-06	3.06E-07
3/17/93 - 2	3.34E-06	4.00E-06	5.96E-06	4.43E-06	1.36E-06
3/17/93 - 3	3.46E-06	3.94E-06	5.61E-06	4.34E-06	1.12E-06
3/18/93 - 4	3.35E-06	4.00E-06	4.84E-06	4.06E-06	7.43E-07
3/18/93 - 5	3.02E-06	3.90E-06	5.12E-06	4.01E-06	1.05E-06

^aInductively coupled plasma atomic emission spectrometry EPA-SW-846-6010.

4.3.6.6. Mercury

Mercury was found on 4 of the 5 trials, (7 out of 15 samples) in very low amounts, Table 4.44. The overall mean was 1.44E-08 with a standard deviation of 1.32E-08.

4.3.6.7. Potassium

Potassium was found on all samples, Table 4.45, with no significant difference in the means detected. The overall mean was 3.03E-03 with a standard deviation of 7.12E-04.

4.3.6.8. Sodium

Sodium was found in all samples in a very uniform amount, Table 4.46. There was no significant difference in the trial means. The overall mean was 5.08E-05 with a standard deviation of 9.30E-06.

Table 4.44 Emission Factors for Mercury with Means and Standard Deviations from the Open Burning of M-3 Propellant as Sampled by Hivol and Assayed by CVAA^a Method.

Date - Trial	HiVol 1	HiVol 2	HiVol 3	Average	Standard Deviation
	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)
3/16/93 - 1	BD ^b	BD	BD	NA ^c	NA
3/17/93 - 2	BD	2.35E-08	BD	NA	NA
3/17/93 - 3	2.81E-08	BD	3.06E-08	2.94E-08	1.73E-09
3/18/93 - 4	2.15E-09	BD	1.21E-09	1.68E-09	6.68E-10
3/18/93 - 5	1.49E-08	6.23E-10	BD	7.76E-09	1.01E-08

^aCold vapor atomic absorption spectrometry EPA-SW-846-7471.

^bBelow detection.

^cNot applicable.

Table 4.45 Emission Factors for Potassium with Means and Standard Deviations from the Open Burning of M-3 Propellant as Sampled by Hivol and Assayed by ICP^a Method.

Date - Trial	HiVol 1	HiVol 2	HiVol 3	Average	Standard Deviation
	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)
3/16/93 - 1	2.19E-03	2.15E-03	2.48E-03	2.27E-03	1.80E-04
3/17/93 - 2	2.51E-03	3.06E-03	4.33E-03	3.30E-03	9.36E-04
3/17/93 - 3	2.60E-03	3.02E-03	4.08E-03	3.23E-03	7.63E-04
3/18/93 - 4	2.52E-03	2.95E-03	3.69E-03	3.05E-03	5.92E-04
3/18/93 - 5	2.59E-03	3.22E-03	4.09E-03	3.30E-03	7.57E-04

^aInductively coupled plasma atomic emission spectrometry EPA-SW-846-6010.

Table 4.46 Emission Factors for Sodium with Means and Standard Deviations from the Open Burning of M-3 Propellant as Sampled by Hivol and Assayed by ICP^a Method.

Date - Trial	HiVol 1	HiVol 2	HiVol 3	Average	Standard Deviation
	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)
3/16/93 - 1	4.13E-05	3.94E-05	4.96E-05	4.34E-05	5.44E-06
3/17/93 - 2	4.60E-05	5.17E-05	7.04E-05	5.60E-05	1.28E-05
3/17/93 - 3	4.33E-05	5.57E-05	6.37E-05	5.42E-05	1.03E-05
3/18/93 - 4	4.19E-05	4.42E-05	5.99E-05	4.87E-05	9.78E-06
3/18/93 - 5	4.31E-05	5.28E-05	5.89E-05	5.16E-05	7.93E-06

^aInductively coupled plasma atomic emission spectrometry EPA-SW-846-6010.

4.3.6.9. Titanium

Titanium was found on 2 out of a total of 15 samples with an EF of 4.06E-07 and 3.57E-07.

4.3.6.10. Zinc

Zinc was found on only one of 15 samples with an EF of 9.68E-06.

4.3.7. Emission Factor for Hydrogen Chloride

The EF for the HCl produced by the open burning of the M-3 propellant was 7.4E-05. The instrument sampled for HCl on the first trial, on the remainder of the M-3 trials the instrument was configured to sample for HCN.

4.3.8. Emission Factor for Hydrogen Cyanide

The EFs for the HCN produced by the open burning of the M-3 propellant were 0.000147, 0.000174, 0.000114, and 0.000154. The mean and standard deviation from these estimates are 0.000118 and 0.0000692, respectively.

4.3.9. Emission Factor for PM10

The EF for the PM10 produced by the open burning of the M-3 propellant were 0.0094, 0.0091, 0.0087, 0.0080, and 0.0082 for trial 1 through 5. The mean and standard deviation from these estimates are 0.0087 and 0.000584, respectively.

4.4. M9 PROPELLANT BURN EMISSION FACTORS

4.4.1. Volatile Organic Compounds

The emission factors for selected volatiles and groups of volatiles compounds are shown in Table 4.47. The complete volatile data package from the assay of the SUMMA™ canisters are included in Appendix F.

4.4.2. Semivolatile Organic Compounds

The semivolatiles were assayed from two collection media; (1) the hivol samplers using 20.3 x 25.4cm quartz fiber filters and the PS-1 samplers using 100mm diameter quartz fiber filters followed by a 60mm i.d. x 125mm borosilicate glass cylinder containing XAD-2® resin. Extraction of the hivol media were done by AWL using the method described in Appendix C, Page C-7. Analyses of hivol media extract were done by EPA Method 8270 using GC/MS and by SFC/MS using the method described in Appendix

Table 4.47 Emission Factors for Volatile Organic Compounds Found During Open Detonation of 40-mm High Explosive Cartridge.

Analyte	DU-73&74
	(wt/wt)
Carbon tetrachloride	2.66E-07
Benzene	3.25E-06
Styrene	4.71E-07
Alkenes (Olefins)	1.69E-05
Aromatics	5.39E-06
TNMHC	1.51E-05
TO-12 (NMOC)	1.03E-04

C, Pages C-11 and C-20. Extraction of the PS-1 media were done by Radian Corp with assay of the extract by EPA Method 8270 using GC/MS, Appendix C, Page C-65.

4.4.2.1. Emission Factors from Hivol Samplers Using SFC/MS Method

Table 4.48 shows the EF for the semivolatiles found by the SFC/MS analyses.

Table 4.48 Emission Factors for Semivolatile Organic Compounds Produced During Open Burning of M9 Propellant, as Sampled by Hivol and Assayed Using SFC/MS.

AWL No.	MNG003	MNG004	MNG005	Average	Standard
Target Analyte	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	Deviation (wt/wt)
N-Nitrosodiphenylamine	1.58E-08	BD	BD	NA	NA
Hexahydro-1,3,5-trinitro-1,3,5-triazine	8.84E-10	8.26E-10	1.52E-09	1.08E-09	3.86E-10
2-Nitropyrene	2.92E-09	4.70E-09	1.10E-08	6.22E-09	4.26E-09
Dibenzofuran	BD	1.56E-08	BD	NA	NA
Diphenylamine	7.44E-10	1.69E-09	BD	1.22E-09	6.69E-10
Benz(a)pyrene	4.78E-09	3.76E-09	2.81E-09	3.78E-09	9.87E-10

4.4.2.2. Emission Factors from Hivol Samplers Using the EPA Method 8270

Table 4.49 shows the EF for the semivolatiles found when using EPA Method 8270.

Table 4.49 Emission Factors for Semivolatile Organic Compounds Produced During Open Burning of M9 Propellant, as Sampled by Hivol and Assayed Using EPA Method 8270.

AWL NO:	MNG 003	MNG 004	MNG 005	Average	Standard Deviation
Analyte	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)
bis(2-Ethylhexyl)phthalate	3.06E-08	6.54E-08	7.76E-08	5.79E-08	2.44E-08
2-Nitrophenol	BD	BD	1.76E-08	BD	BD
4-Nitrophenol	6.21E-07	1.01E-06	1.22E-06	9.51E-07	3.04E-07

4.4.2.3. Emission Factors from PS-1 Samplers Using the EPA Method 8270

Table 4.50 shows the EF for the semivolatiles found when using the EPA Method 8270.

Table 4.50 Emission Factors for Semivolatile Organic Compounds Produced During Open Burning of M9 Propellant, as Sampled by PS-1 and Assayed Using EPA Method 8270.

Radian Field ID	SVOC-9-2	SVOC-9-4	SVOC-9-5	Average	Std. Dev.
	EF	EF	EF	EF	EF
	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)	(wt/wt)
Acetophenone	3.34E-06	5.08E-06	2.54E-06	3.65E-06	1.30E-06
2-Nitrophenol	1.23E-06	1.45E-06	8.97E-07	1.19E-06	2.79E-07
a,a-Dimethylphenethylamine	1.61E-07	1.57E-07	BD	1.59E-07	2.49E-09
1,2,4-Trichlorobenzene	1.76E-07	BD	7.48E-08	1.25E-07	7.14E-08
Naphthalene	2.91E-07	6.29E-07	BD	4.60E-07	2.39E-07
2-Methylnaphthalene	1.30E-07	1.08E-07	BD	1.19E-07	1.55E-08
Dimethyl phthalate	BD	5.20E-07	BD	NA	NA
Acenaphthylene	8.79E-08	1.09E-07	4.49E-08	8.06E-08	3.26E-08
4-Nitrophenol	1.05E-06	1.09E-06	7.48E-07	9.64E-07	1.88E-07
Diethyl phthalate	1.61E-05	2.86E-06	6.72E-07	6.56E-06	8.37E-06
Phenanthrene	1.30E-08	3.01E-07	BD	1.57E-07	2.04E-07
di-n-Butyl phthalate	1.46E-07	3.58E-06	BD	1.86E-06	2.43E-06
Butyl benzyl phthalate	BD	1.57E-07	BD	NA	NA
di-n-Octyl phthalate	BD	3.01E-07	BD	NA	NA

4.4.3. GC/MS New Compounds of Potential Interest

MSA conducted an extensive library search of compounds found by GC/FS/MS.

4.4.4. SFC/TEA and SFC/MS New Compounds of Potential Interest

Composite filter extracts were analyzed by SFC/TEA. The TEA is a chemiluminescence detector that is sensitive and selective for nitro- and nitroso-containing compounds and nitrate esters. SFC/TEA operating procedures are contained in AWL LOI-8. The TEA is useful for detection of analytes that may be by-products of explosives detonations. From the retention times of standards, peaks in the SFC/TEA chromatograms can be tentatively identified and/or selected for analysis by SFC/SIM/MS. This method is capable of detecting very low levels of target analytes in complex mixtures. It is especially suited to the analysis of these compounds, which will not survive the temperatures necessary for GC/MS analysis. This analyses shows from 3 to 4 nitro-compounds present but not identified (no SFC/MS library spectra exists for comparing unknowns). The complete list of compounds with analyte concentrations (calculated from hexahydro-1,3,5-trinitro-1,3,5-triazine relative response factors) are in, Appendix 6, pages 1 and 2 of AWL Report.

4.4.5. Metals

The energetic material in the M9 Propellant contained potassium nitrate as 1.5 percent of the total weight of 2400 g. The EF for the elements found are given in Table 4.51.

Table 4.51 EF for Elements Produced During OB of M9 Propellant, as Sampled by Hivol.

Element	Hivol 1 (wt/wt)	Hivol 2 (wt/wt)	Hivol-3 (wt/wt)	Average (wt/wt)	Std. Dev. (wt/wt)
Aluminum	3.01E-06	4.13E-06	6.02E-06	4.39E-06	1.52E-06
Cadmium	4.02E-07	6.95E-07	7.05E-07	6.01E-07	1.72E-07
Calcium	6.37E-05	7.32E-05	8.22E-05	7.31E-05	9.25E-06
Copper	5.23E-06	6.19E-06	7.96E-06	6.46E-06	1.39E-06
Lead	1.06E-06	7.51E-07	1.20E-06	1.01E-06	2.31E-07
Potassium	4.43E-03	5.07E-03	6.22E-03	5.24E-03	9.07E-04
Sodium	5.31E-05	5.82E-05	8.02E-05	6.39E-05	1.44E-05
Titanium	2.48E-07	2.63E-07	2.81E-07	2.64E-07	1.65E-08

4.4.6. Emission Factor for Hydrogen Chloride

The EF for the HCl produced by the open burning of the M9 propellant was 7.54E-05.

4.4.7. Emission Factor for PM10

The EF for the PM10 produced by the open burning of M9 propellant was 0.0155.

4.5. DISCUSSION

4.5.1. M-3

4.5.1.1. Volatiles

The volatiles are all summarized in Table 4.3. Additionally compounds that were also selected for EF calculation were vinylchloride, chloroform, 1,3-butadiene, and styrene. None of these compounds were ever quantified above background level. As an example: using benzene, which is classified as a carcinogen, the average EF of $1.34\text{E-}05$, burning one metric ton of M-3 would produce 13.4 g of benzene for a source parameter for downwind diffusion.

4.5.1.2. Semivolatiles

The selected semivolatiles for discussion was limited to those in the AEHA Test Plan as target analytes for semivolatiles.

4.5.1.2.1. 2,4-Dinitrotoluene

2,4-Dinitrotoluene was found in all samples (15 total) from the Hi-Vol by the SFC/MS method, on 13 of 15 samples from the Hi-Vol by the GC/MS procedure, and on 14 of 15 samples from the PS-1 by the GC/MS procedure. The means are shown in Table 4.52. As an example: using the average EF of $6.21\text{E-}06$, burning one metric ton of M-3 would produce 6.21g of 2,4-Dinitrotoluene for a source parameter for downwind dispersion.

4.5.1.2.2. 2,6-Dinitrotoluene

2,6-Dinitrotoluene was an analyte for all samplers/procedures and not detected by in any sample.

4.5.1.2.3. 4-Nitrophenol

4-Nitrophenol was not a target analyte for the SFC/MS procedure. It was an analyte on the EPA Method 8270 list and found by the Hi-Vol sampler using the GC/MS procedure on 8 of 15 samples with a mean

Table 4.52 Summary of Emission Factor Means for Selected Semivolatile Target Analytes.

Target Analyte	Hi-Vol ^a		PS-1 ^b
	SFC/MS ^c	GC/MS ^d	GC/MS
2,4-Dinitrotoluene	3.58E-07	1.55E-07	6.21E-06
2,6-Dinitrotoluene	BD ^e	BD	BD
4-Nitrophenol	NA ^f	2.58E-07	BD
2-Nitronaphthalene	BD	NA	NA
2,4,6-Trinitrotoluene	1.22E-08	NA	NA
Phenol	BD	BD	2.01E-06
Dibenzofuran	4.46E-08	BD	7.73E-08
Benzo(a)pyrene	7.71E-09	BD	BD
N-Nitrosodiphenylamine	2.68E-08	BD ^g	BD ^g
Nitroglycerin	NA	NA	NA

^aHigh-volume sampler.

^bFilter paper backed-up by a XAD™-2 resin bed.

^cSupercritical fluid chromatography/mass spectrometry.

^dGas chromatography/mass spectrometry.

^eBelow detection.

^fNot an analyte.

^gIf present detected as diphenylamine.

EF of 2.58E-07. It was below detection on all samples collected by the PS-1 sampler.

4.5.1.2.4. 2-Nitronaphthalene

2-Nitronaphthalene was an analyte for the SFC/MS procedure; however, it was not detected in 15 samples. It was not an analyte for the GC/MS procedure.

4.5.1.2.5. 2,4,6-Trinitrotoluene

2,4,6-Trinitrotoluene was detected on all 15 samples by the SFC/MS procedure. It was not a target analyte on the EPA Method 8270 list for the GC/MS procedure.

4.5.1.2.6. Phenol

Phenol was detected on 10 of 15 samples from the PS-1 sampler with a mean EF of 2.01E-06. Phenol was not detected from the Hi-Vol samples. The laboratory performing the extraction of the Hi-Vol filters stated that phenol may have been lost in the extraction process.

4.5.1.2.7. Dibenzofuran

Dibenzofuran was found on 8 of 15 samples from the Hi-Vol by the SFC/MS method; it was not detected on any samples from the Hi-Vol by the GC/MS procedure; and it was found on 4 of 15 samples from the PS-1 by the GC/MS procedure. The EF means are shown in Table 4.52.

4.5.1.2.8. Benzo(a)pyrene

Benzo(a)pyrene was found on 15 of 15 samples by the SFC/MS procedure with an EF of 7.71E-09. It was not detected by the GC/MS procedure.

4.5.1.2.9. N-Nitrosodiphenylamine

N-Nitrosodiphenylamine was found on 15 of 15 samples by the SFC/MS procedure with an EF of 2.68E-08. N-Nitrosodiphenylamine which is detected as diphenylamine by the GC/MS procedure was not detected.

4.5.1.2.10. Nitroglycerin

Nitroglycerin was not a target analyte on any of the procedures.

4.5.1.3. Metals

Copper and lead were listed in the AEHA Test Plan as the target analytes. These were both found in all samples with an overall EF of 4.23E-06 for copper and 4.07E-06 for lead. This would equate to approximately 0.01g for 2400g of propellant material burned.

4.5.1.4. Effect of Temperature and Humidity

Trials 1 and 3 had essentially the same temperature ranges (12 to 25°C) and the same relative humidity (RH) range (32 to 42%), so these trials could be considered as replicataions. Trial 2 had a higher temperature than the other four trials. Trial 4 and 5 had higher relative humidity. As noted in paragraph 4.3.2 and subsequent paragraphs there were a few compounds that showed significant differences in the trial means; however, there was no clear behavioral pattern and in most cases no significant difference

in the trial means within a compound. Based on the results of this test an effect due to temperature and /or relative humidity cannot be substantiated. Additional testing and a statistical design to address temperature and humidity would be required for a more definitive conclusion.

4.5.2. M-9

The reader is referred to paragraph 4.4 for the results of the one Trial of M-9 burn. In general it can be said that fewer volatile and semivolatile compounds of interest were detected.

SECTION 5 QUALITY ASSURANCE ACTIVITIES

NOTE: Since both the US Air Force (USAF) as well as the Massachusetts National Guard (MNG) testing took place with little time separating the two projects, the QA information derived from testing for the USAF also applies to the MNG program.

5.1 General

Staff from the U.S. Environmental Protection Agency's Atmospheric Research and Exposure Assessment Laboratory (AREAL), Research Triangle Park, NC conducted 16 systems audits and two performance audits on the organizations collecting and/or analyzing emission samples from the Dugway Proving Ground(DPG) BangBox (BB) testing operations. The purpose of these audits was to verify for the project officer that the sample collection/analysis and data reduction/reporting/archiving activities were conducted in compliance with documented procedures previously reviewed and approved by the project officer.

5.2 Results from the Systems Audits

5.2.1 Overview

The organizations audited and the dates of the audits are presented in Table 5.1. Detailed descriptions of the findings from each audit are contained in Appendix D. These audits focused primarily on overall practices including maintenance of logbooks; completeness/security of records; instrument calibration/maintenance and sample handling/chain-of-custody. When changes to existing operations were recommended by the auditors, follow-up visits ensured that these changes had been made or that a sound rationale existed for continuing with the in-place system.

5.2.2 Results for Alpine West Laboratories (AWL)

5.2.2.1 Basis for Audits

The basis for the systems audits was AWL's Letters of Instruction (LOIs) described in the draft test design plan, Characterization of Emissions Resulting from Thermal Treatment of Selected Propellants and Explosive Munitions, September, 1992 (Reference 19). The AWL LOIs were dated August 7,1992, and covered all AWL activities associated with AWL's contract with DPG for the munitions and propellants testing programs (See Appendix C, Pages C2-C20).

Table 5.1 Schedule of System Audits

Organization Name	Date of Audit
Alpine West Laboratories (AWL)	3 December 1992
	11 February 1993
	16 March 1993
	18 August 1993
Dugway Proving Ground (DPG)	10 February 1993
	16-17 August 1993
Mountain State Analytical Lab (MSA)	11 February 1993
	16 March 1993
	18 August 1993
Oregon Graduate Institute (OGI)	16 February 1993
	24 August 1993
Radian Corporation (Radian)	15 October 1992
	15 January 1993
	3 March 1993
	30 March 1993
	14 September 1993

5.2.2.2 AWL Activities

AWL has a contract with Dugway Proving Ground (DPG) Dugway, UT, to collect the particles and semi-volatiles released when munitions and propellants are detonated and burned in the DPG BangBox. The particles and semi-volatiles are collected on 8 X 10 inch quartz fiber filters using standard hi-volume samplers operated by DPG personnel. AWL is responsible for: pre-treating the filters to remove contaminants, placing the filters in and removing them from the samplers, transporting the filters to AWL's facilities in Provo, UT, determining the weight gain of the filters, extracting the filters in a Soxhlet extractor, and analyzing the extract for the target semi-volatile by supercritical fluid chromatography/gas chromatography (SFC/MS). They are also responsible: for analysis by gas chromatography/mass spectrometry (GC/MS); and for cutting a small square from each filter before it is extracted, and for the analysis of these filter cuttings for metals.

5.2.2.3 Significant Findings

a. A pretest audit conducted in December 1992 determined that AWL had made significant improvements in their filter preparation procedure but had not updated their LOI to show this change. AWL updated the LOI before the actual test (February 1993) and kept their LOIs up-to-date thereafter.

b. During the second audit (February 1993), which was done while AWL was analyzing samples from the BangBox, AWL was observed to be using abbreviated sample identification numbers on the filter extracts. Although all samples were still readily identifiable, the auditor suggested that AWL use unabbreviated sample identification numbers on all samples. AWL agreed with this recommendation and made the changes immediately.

c. It was also determined during this second audit that there was confusion at AWL on how the filters were to be combined. The confusion resulted because the original scheme (one filter would be used for all three test runs) could not be accomplished because of the large decrease in sampler flow rate over the first run. There was also confusion concerning how the extracts were to be split with Radian. A meeting was held with the DPG project officer (D. Johnson), the AWL project manager (M. Lee) and the auditor to resolve the confusion. At the end of the meeting the auditor recommended that the AWL project manager put in writing his understanding of how AWL was to combine the filters and split the extracts. This was done and in the view of the auditor no samples were lost or combined incorrectly.

d. AWL's documentation and chain-of-custody procedures continued to improve over the course of the project. The last audit (August 1993) showed that all documentation related to the USAF and the MNG projects were complete and in good order. In the opinion of the auditors, AWL has properly and accurately documented how the samples were collected, analyzed and reported.

5.2.3 Results of Dugway Proving Ground (DPG)

5.2.3.1 Basis for Audits

The basis for the systems audit was Letters of Instructions (LOIs) described in the draft test design plan, "Characterization of Emissions Resulting from Thermal Treatment of Selected Propellants and Explosive Munitions", September, 1992. The LOIs were dated August 7, 1992, and covered all DPG activities associated with the USAF munitions and propellants testing project.

5.2.3.2 DPG Activities

DPG staff calibrate and operate the three high volume samplers used to collect semi-volatile compounds for subsequent extraction and analysis by Alpine West Laboratories. They also calibrate and operate CO₂, CO, O₃, NO_x, and SO₂ continuous monitors (1 each) monitoring the concentrations of these pollutants in the BangBox at DPG. The output from the gaseous pollutant monitors and the flow-rate of the high volume samples are recorded on a Bernoulli disk in a PC-based system. The data on the Bernoulli disk are then dumped to a VAX system for subsequent data reduction.

5.2.3.3 Significant Findings

a. The first audit (February 1993) was done when DPG staff were measuring the emission products from the detonations of the USAF munitions. The audit determined that DPG staff had correctly calibrated and were operating the CO₂, CO, O₃, NO_x (NO, NO₂) and SO₂ and high volume samplers in accordance with their LOIs. A visual scan of the gas monitors' and the high volume samplers' voltage outputs (as presented on the PC monitor) showed that the instruments were performing as expected. At the time of the audit, no data had been transferred from the Bernoulli disk to the VAX system, so it was not possible to assess how accurately the gaseous pollutant monitor/high volume sampler data were being recorded. However, the DPG staff were aware that all data collection, transfer and reduction activities needed to be validated and the validation activities carefully documented as to time, place

and results found.

b. The second audit (August 1993) found no evidence that the data collection, transfer and reduction activities had been validated. The DPG staff responsible for collecting the data could not provide written documentation on how the gaseous pollutant monitor output voltages had been converted to concentration units. The log books were incomplete and there was no supporting documentation to indicate what procedures had been followed. Thus, the accuracy of the emission factors calculated from the DPG gas monitors cannot be ascertained. In contrast, due to the herculean efforts of the project officer and his contractor personnel assisting him, the flowrate and sample volume calculations for the high volume samplers are all adequately documented. Thus, the emission factors for the semi-volatile and the metals from the high volume samplers appear to be valid.

5.2.4 Alpine West Laboratory (AWL)/Mountain State Analytical Laboratories (MSA)

5.2.4.1 Basis for the Audits

The basis for the systems audits was AWL's Letters of Instruction (LOIs) described in the draft test design plan, Characterization of Emissions Resulting from Thermal Treatment of Selected Propellants and Explosive Munitions, September, 1992 (Reference 19). The AWL LOIs were dated August 7, 1992 (See Appendix C, Pages C2-C20).

5.2.4.2 AWL/MSA Activities

MSA has an agreement with AWL to analyze extracts of the high volume filter for semi-volatile using gas chromatography/mass spectrometry (GC/MS) and to analyze a portion of each unextracted high volume filter for metals.

5.2.4.3 Significant Findings

The auditors were very impressed with the operation of this laboratory. MSA's documentation, record keeping, and archival of data under chain-of-custody procedures are close to perfection.

5.2.5 Oregon Graduate Institute(OGI)

5.2.5.1 Basis for the Audits

The basis for the systems audits was OGI's Letters of Instruction (LOIs) described in the "Final Report U.S. Army Armament, Munitions and Chemical Command, Development of Methodology and Technology for Identifying and Quantifying Emission Products from Open Burning and Open Detonation Thermal Treatment Methods", January, 1992 (Reference 17), and an SOP dated February 12, 1993.

5.2.5.2 OGI Activities

OGI has a contract with Dugway Proving Ground, Dugway, UT, to collect volatile organic compounds (VOCs) released when munitions and propellants are detonated and burned in the DPG BangBox. The samples are collected in evacuated, stainless steel, electropolished Summa canisters in accordance with EPA's TO-14 Method. OGI personnel are responsible for: cleaning the canisters to remove contaminants transporting the canisters to DPG, collecting samples at DPG, analyzing these samples for VOCs (Method TO-14) and for total non-methane organics (Method TO-12), and maintaining logbooks and records in accordance with chain-of-custody procedures. OGI also operated a continuous HCN and HCl monitor at DPG during the tests and analyzed OGI's canisters for CO and CO₂.

5.2.5.3 Significant Findings

During the first audit (February 1993) the auditor recommended some improvements in documentation and record keeping. These improvements were made. The final audit (August 1993) found that OGI had compiled all the reports and the pertinent data for the project into a neat, well-organized data package. The documentation was stored in a secure area and OGI had done an excellent job backing up their computerized records and data.

5.2.6 Radian Corporation

5.2.6.1 Basis for the Audits

The basis for the systems audit is Radian Corporation's LOIs dated October 16, 1992.

5.2.6.2 Radian Activities

Radian Corporation has a contract with Dugway Proving Ground, UT, to collect particles and semi-volatile organic compounds (SVOCs) released when propellant and munitions are detonated and burned in the DPG BangBox. The particles and SVOCs are collected using a General Metals Works PS-1 sampler equipped with four-inch diameter quartz fiber filter

and a boro-silicate glass cartridge containing XAD-2 resin. Radian Corporation is responsible for: preparing the filter and XAD-2 resin for use, supplying and operating the PS-1 samplers, transporting the collected samples to the Radian Corporation facilities at Morrisville, NC for extraction/analyses for the target SVOCs by gas chromatography/mass spectrometry (GC/MS). They are also responsible for analyzing portions of the PS-1 and high volume extracts for munitions and propellant residues using High Pressure Liquid Chromatography (HPLC).

5.2.6.3 Significant Findings

a. During the first audit (December 1992) Radians workload was very light, so the analyst decided to use abbreviated sample identification numbers for the extracts from the November pilot test samples. The auditor recommended using complete identification numbers for all samples all the time. Radian management agreed to this and complied with this recommendation throughout the project. The auditor also observed that some of the analysts were lax about completing the work-sheets associated with field samples. When this was pointed out to the Radian management, they agreed to correct the situation. The second audit (January 1993) found that all work-sheets and records were complete.

b. The last audit (September 1993) found that Radians's documentation on the project was very good and well organized.

5.3 Results from the Performance Audits

5.3.1 Overview

AREAL conducted performance audits on OGI. In these audits OGI identified the VOCs and their concentrations in a canister and a cylinder sent to them by AREAL. OGI identified and quantified the VOCs in the audit samples using the same analytical procedures they used to analyze the canisters containing the emissions products from the detonation of the USAF munitions at DPG. Performance audits could not be done on the other organizations either because of scheduling constraints (gaseous pollutant monitors and high volume samplers) or because no well-characterized audit samples were available (HCN, HCl, semi-volatile, metals) that accurately simulated the emission samples being collected.

5.3.2 Results from First Performance Audit

In the first audit, which was done in December, 1992, OGI analyzed a pressurized canister containing approximately 20 VOCs at concentrations between 4 and 60 ppbv. OGI used

GC/MS to identify the seven, TO-14 VOCs that were present in the low ppbv concentration range. The TO-14 components in the master gas mixture that was used to prepare the audit sample had been certified against a gas mixture traceable to the National Institute for Standards and Technology (NIST). The uncertainty in these analytical values was approximately 1 ppbv. As shown in Table 5.2, OGI achieved very good results in this audit: many of OGI's values are within the uncertainty ranges of the NIST-traceable certified concentrations.

5.3.3 Results from Second Performance Audits

The second audit (March 1993) was done while OGI was actually analyzing canisters containing the emission products from the detonation of the USAF munitions at DPG. In this audit OGI received a 1.5L compressed gas cylinder containing 27 VOCs in the concentration range of 1 to 8 ppbv. OGI transferred an aliquot of this mixture to one of their canisters and analyzed the canister's contents by GC/MS and GC/FID. Most of the 27 compounds in the audit sample were either representative of those commonly found in the ambient air or would likely be formed when munitions were detonated. As shown in Table 5.3, OGI achieved excellent results on this complex mixture. Carbon tetrachloride was the only analyte for which OGI's results differed markedly from the expected concentration.

Table 5.2 Results from Second Performance Audits on OGI (ppbv)

Compound	Expected	Found	Difference
1,1,1-Trichloroethane	4.1	6.5	2.4
1,1-Dichloroethane	4.0	3.3	-0.7
1,2-Dichloropropane	2.4	1.7	-0.7
3-Methylpentane	4.8	4.3	-0.5
Benzene	7.3	6.6	-0.7
Butane	5.3	4.6	-0.7
Carbon Tetrachloride	3.4	13.6	-10.2
Chlorobenzene	1.8	1.0	-0.8
Chloroform	3.5	5.7	-2.2
Ethane	3.8	4.5	0.7
Ethylbenzene	1.9	1.1	-0.8
Freon 11	3.6	5.3	1.7
Heptane	4.7	4.3	-0.4
Hexane	4.9	4.4	-0.5
i-Butane	5.2	4.4	-0.8
i-Pentane	5.3	4.5	-0.8
Methylene Chloride	2.7	2.4	-0.3
o-Xylene	4.3	2.3	-2.0
Octane	4.4	4.3	-0.1
Pentane	5.0	4.5	-0.5
Propane	5.1	4.5	-0.6
t-1,2-Dichloroethylene	2.8	3.1	0.3
Tetrachloroethylene	3.7	3.4	-0.3
Toluene	5.4	4.6	-0.8
Trichloroethylene	7.2	6.9	-0.3
Vinyl Chloride	3.4	3.5	0.1
Vinylidene Chloride	3.5	4.0	0.5

Table 5.3 Results from First Performance Audit on OGI (ppbv)

Compound	Expected	Found	Difference
Vinyl Chloride	9.4	7.6	-19
Bromomethane	8.3	9.8	18
1, 2-Dichloropropane	5.0	5.0	0
1, 2-Dibromoethane	6.7	7.0	5
Ethylbenzene	4.8	5.4	12
o-Xylene	5.6	4.5	20
Vinylidene Chloride	9.0	11.5	28

APPENDIX A REFERENCES

1. Letter Approving Open Burning Application #SM-85-092-M, 8 January 1987, Department of Environmental Quality Engineering, Commonwealth of Massachusetts, Southeast Regions.
2. Memorandum, USAEHA, HSHB-MO-O, 17 May 1991, subject: Multidisciplinary Study No. 65-32-0716-91, Health Risk Assessments Concerning Open Burning of Gun Propellants, Camp Edwards, Massachusetts, April-May 1991.
3. Memorandum for Record, USAEHA, HSHB-ME-AQ, 10 September 1991, subject: Meeting at Camp Curtis Guild among Ms. Eleanora Babij and COL Stockhaus, Massachusetts National Guard; Mr. Peter Kahn, EPA Region I; Mr. Tom McGrath, Massachusetts DEP; and 1st Mona Caesar and Mr. James Wood, USAEHA.
4. Final Report, Upper Cape Cancer Incidence Study, Boston University-School of Public Health, January 1992.
5. Letter, Agency for Toxic Substances and Disease Registry, March 5, 1992, subject: Propellant Bag Burning Otis Air National Guard Base.
6. Memorandum, USAEHA, HSHB-ME-AQ, 4 February 1992, subject Air Monitoring Plan for Open Burning Combustion Products, Air Quality Assessment No. 43-21-N700-92, Camp Edwards, Massachusetts, January 1992.
7. Letter, U.S. Environmental Protection Agency Region I, March 11, 1992, concerning recommendations for incorporation into the final air monitoring protocol.
8. Letter, Commonwealth of Massachusetts, Depart of Environmental Quality Engineering, March 10, 1992, subject Edwards Air Monitoring Protocol.
9. Letter, USAEHA, Air Pollution Engineering Division, April 20, 1992, concerning information summarizing USAEHA's experience using XAD-2 resin to capture dinitrotoluene.
10. Letter, EPA Region I, May 5, 1992, concerning EPA's review of supplemental information on XAD-2 resin extraction and analytical procedures for dinitrotoluene isomers and nitroglycerin.
11. Memorandum, USAEHA, HSHB-ME-AQ, 8 June 1992, subject: Air Monitoring Plan

for Open Burning combustion Products, Air Quality Assessment No. 43-21-N700-92, Camp Edwards, Massachusetts, June 1992.

12. Letter, U.S. Environmental Protection Agency Region I, June 16, 1992, concerning recommendations for incorporation into the final air monitoring plan.

13. Letter, Massachusetts Department of Environmental Quality Engineering, June 17, 1992, subject: Camp Edwards Air Monitoring Protocol.

14. Letter, Massachusetts Department of Public Health, June 23, 1992, concerning recommendations for incorporation into the final air monitoring plan.

15. Letter, Massachusetts Departments of Environmental Protection and Public Health, June 30, 1992 concerning an information paper on the air monitoring plan for the open burning of excess propellants at Camp Edwards.

16. U.S. Army Armament, Munitions and Chemical Command, Rock Island, Illinois, Final Report Development of Methodology and Technology for Identifying and Quantifying Emission Products from Open Burning and Open Detonation Thermal Treatment Methods, BangBox Test Series, Volume 1 Test Summary, Volume 2 Test Development, Volume 3 Quality Assurance and Quality Control, January 1992.

17. U.S. Army Armament, Munitions and Chemical Command, Rock Island, Illinois, Final Report Development of Methodology and Technology for Identifying and Quantifying Emission Products from Open Burning and Open Detonation Thermal Treatment Methods, Field Test Series A, B, and C, Volume 1 Test Summary, Volume 2 Part A Appendices, Volume 2 Part B Appendices, January 1992.

18. Memorandum, USAEHA, HSHB-ME-AQ, 1 February 1993, subject: Test Design Plan for Camp Edwards Propellant Burning, Project No. 43-21-N700-93, Bang Box Facility, Dugway Proving Ground, Utah, January 1993.

19. Detailed Test Plan, Characterization of Open Burning and Open Detonation Thermal Treatment Combustion Products, Dugway Proving Ground, Dugway Utah, March 1993

APPENDIX B. ABBREVIATIONS

AMCCOM	U.S. Army Armament, Munitions and Chemical Command, Rock Island, Illinois
AP	antipersonnel
AREAL	U.S. Environmental Protection Agency Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, North Carolina
AWL	Alpine West Laboratories, Provo, Utah
BB	BangBox
CP	command post
CTG	cartridge
DAP	data acquisition program
DAS	data acquisition system
DPG	U. S. Army Dugway Proving Ground, Dugway, Utah
EF	emission factor
hi-vol	high-volume
HMX	octamethylenehexanitramine
HPLC	high performance liquid chromatograph(y)
LOI	letter(s) of instruction
MS	mass spectrometer <i>or</i> mass spectrometry
MTD	Material Test Directorate, U.S. Army Dugway Proving Ground, Dugway, Utah
NA	not applicable
ND	not detected
NEW	net explosive weight
OB	open burning
OD	open detonation
OGI	Oregon Graduate Institute of Science and Technology, Beaverton, Oregon
PEP-TTET	propellant, explosive, and pyrotechnic thermal treatment evaluation and test facility
QA	quality assurance
QC	quality control
RCRA	Resource Conservation and Recovery Act
RDX	hexamethylenetrinitramine
ReF	reference flow
SF ₆	sulfur hexafluoride tracer gas
SFC	supercritical fluid chromatograph(y)
STP	standard temperature and pressure

SVOC	semivolatile organic compound
TNT	trinitrotoluene
TSC	technical steering committee
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compounds

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